ELECTRICAL COMMUNICATION

Technical Journal of the

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION

and Associate Companies

WESTERN HEMISPHERE I. T. & T. SYSTEM COMMUNICATION CONTRIBUTIONS OF 1942

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TRAIN ORDERS BY FACSIMILE TELEGRAPHY

A MACHINE FOR CALCULATING THE POLAR DIAGRAM OF AN ANTENNA SYSTEM

NEW 50-KILOWATT CBS INTERNATIONAL BROADCASTERS

DEHYDRATION OF FOOD BY RADIO FREQUENCY ENERGY

THIN CASE HARDENING WITH RADIO-FREQUENCY ENERGY

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Technical Journal of the
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and Associate Companies

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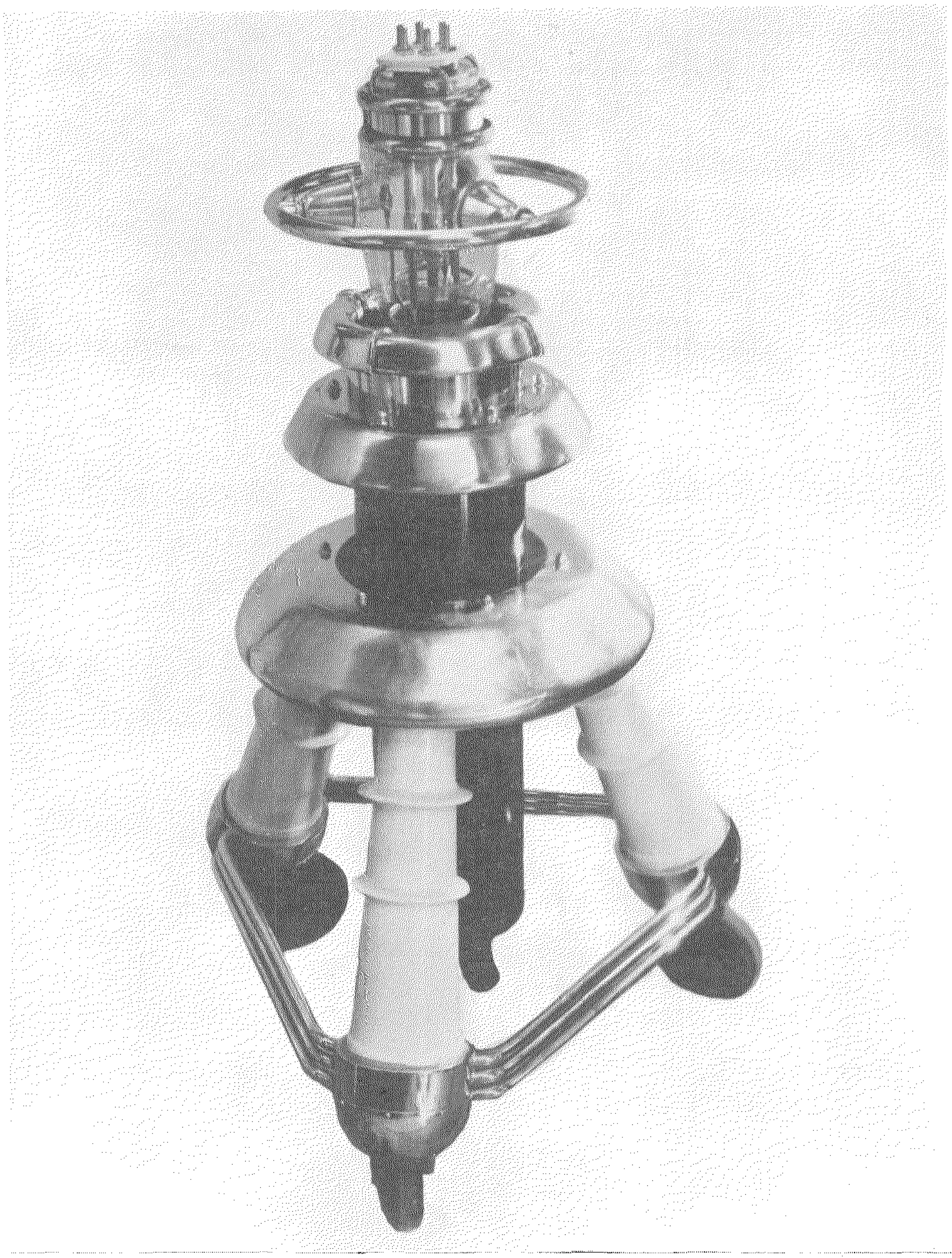

HUGE VACUUM TUBE DESIGNED BY I. T. & T. TWO TUBES ARE CAPABLE OF DELIVERING 200 KILOWATT CARRIER ON SHORTWAVE RADIO-TELEPHONY. THE HEIGHT OF THE TYPE WITH SUPPORTING "TRUCK," SHOWN IN THE ILLUSTRATION, IS FIVE FEET; THAT OF THE TUBE ITSELF IS FOUR FEET.

PLANS FOR THE PRODUCTION OF THESE TUBES ARE BEING FORMULATED.

Western Hemisphere I. T. & T. System Communication Contributions of 1942

UNTIL the War is won by the United Nations a comprehensive communications Annual Review, international or even national in scope, is obviously impossible. Despite wartime restrictions it is, however, becoming apparent that International Telephone and Telegraph System research and development activities abroad and at home, as well as contributions to Western Hemisphere communication networks, including telephone, telegraph and radio, are yielding increasingly advantageous results—directly in connection with the war effort as well as in their long range cultural and industrial implications.

In 1942 the Federal Telephone and Radio Corporation was formed as a result of merging the Federal Telegraph Company and the International Telephone and Radio Manufacturing Corporation. Since the attack on Pearl Harbor on December 7, 1941, its manufacturing facilities have been greatly expanded for war production. As in the case of other I. T. & T. Associate Companies, notably Standard Telephones and Cables Ltd., London, description of new Federal products must in general be deferred. Nevertheless, mention of a number of important developments, despite their association with the war effort, is permissible; references to such developments comprise the major portion of the present review.

Research

Commencing with 1911, when commercial radiotelegraph working with sustained or undamped waves utilizing Poulsen's high efficiency arc generator was introduced in America, the Federal Telephone and Radio Corporation and its predecessor companies, frequently in collaboration with the Mackay Radio & Telegraph Company, have made important contributions resulting from research and development. In 1940, it was felt that the increasingly threatening international situation demanded expansion of International Telephone and Telegraph System research in the U. S. A. Fortunately, it was possible to transfer several of the leading engineers of the European Laboratories to the United States for the purpose of forming the nucleus of a group devoted to research. The wisdom of this move became evident immediately after the entry of the United States into the war inasmuch as this growing research group was called on by the armed services and the National Defense Research Committee to undertake a large number of development contracts. The nature of these developments and their contribution to the war effort must necessarily remain a secret at least until hostilities have ended.

It is recognized that a technological war is now being waged, in which communications and electronics play a most important rôle. Taking advantage of the nucleus of high grade technicians and a background of experience in the forefront of communications it was possible to build up, within a period of months, a capable and effective research organization that ordinarily would have required the same number of years to consummate. The value of its contributions to the war effort is evidenced by the fact that on March 27th, 1943, the Laboratories Division of the Federal Telephone and Radio Corporation was notified that it had been awarded an Army-Navy "E" in recognition of its record of accomplishments.

During the world war of 1914–1918, intensive activities in the communication field resulted within a relatively brief period in developments that under normal conditions would have materialized only after many years. Thus, the rapid development of radio broadcasting, long distance radiotelephony, etc., were the commercial realizations of this basic war effort. Similarly, it is to be expected that the even more revolutionary developments now taking place behind the closed doors of laboratories throughout the country will result in great changes in industrial and private life. While the F. T. R. Laboratories' present efforts are being devoted 100 per cent to war work, it will follow inevitably that the knowledge gained and the new devices developed will prove important in the future peacetime world.

Federal Telephone and Radio Expansion

Rapid expansion in production by the Federal Telephone and Radio Corporation necessitated renting quarters in buildings scattered over the Newark, New Jersey, area. Following careful study of the possibilities, the decision was reached to purchase property for the erection of buildings which would eventually house all I. T. & T. manufacturing activities in the U. S. A. Accordingly, a 120 acre site in Nutley and Clifton, New Jersey, was acquired.

Colonel Sosthenes Behn, President of the International Telephone and Telegraph Corporation, presided at the ground breaking ceremonies attended by I. T. & T. and F. T. & R. officials (February 17th, 1943). In dedicating the first unit, which will be devoted wholly to the prosecution of the war, he stated that it "will be built on the Clifton side of Kingsland Road, and you may rest assured that its architectural design will be entirely in keeping with these beautiful surroundings—something of which the community may well be proud."

"We expect to break ground soon across the road," Colonel Behn continued, "for the construction of a Laboratory, also to be dedicated to our war effort." In visualizing the future of the Company, Colonel Behn expressed the hope that the new Laboratory would carry the development of the science of electronics "to previously unattained heights."

Rotary Machine Switching Equipment

As a result of the outbreak of war in Europe in 1939, arrangements were made to manufacture the well-known Rotary Machine Switching System in the U. S. A. In 1942 Federal Telephone and Radio started shipments of Rotary equipment directed towards the completion of the large central office projects for San Juan, Puerto Rico, and three new central offices for the Rio de Janeiro area. All of these projects will utilize the 7A-2 Rotary Machine Switching System and will incorporate the most up-to-date features available. The San Juan installation includes a 20-position toll and international switchboard, as well as information and complaint desks and associated facilities. When this new exchange is cut into service the Porto Rico Telephone Company, an I. T. & T. associate, will be in a position to meet necessary service demands of the important San Juan defense area.

The three central offices[1] for the Rio de Janeiro area of the Brazilian Telephone Company comprise offices "32," "37" and "49." A new building is being constructed for office "37" while offices "32" and "49" represent additional units for existing central offices. The Rio de Janeiro area is served by the Rotary System; the offices now in process of manufacture will contain equipment identical to that supplied by the Bell Telephone Manufacturing Company, Antwerp. Special desks and test bays are included in these projects.

Simplified Subscribers' Telephone Sets

A new telephone set of revolutionary design was made available during the past year.[2] Loose wiring is avoided by means of a plastic connecting block provided with screw terminals to which the component units—induction coil, condenser, and ringer—make connection through spade lugs rather than by means of wires soldered to lugs on each unit. Interconnection between the terminals is made through bus bar wiring run in grooves on the underside of the connecting block. The gravity switch and plunger are also built integral with this block. Since each unit fits only into its correct position, wrong connections are impossible.

Cellulose acetate sheet and plastics are substituted for paper, fiber, and textile insulation; the gravity switch and dial are equipped with dual, parallel-connected, precious metal contacts and are covered for dust protection.

The cord problem, representing one of the largest items of maintenance, also has been solved by the development of a plastic sheathed, snarl-proof tipless cord. The new cord is simply cut to length and connected without further preparation, that is, the ends require no stripping or soldering. The cord is connected almost automatically and is securely anchored by a new type of screwdown adapter.

Thus, repairs and replacements on the new subsets can be made with minimum difficulty and

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[1] "Conversion of Brazilian Capital to Full Rotary Automatic Operation," by W. Hirsch and E. A. Brander, *Elec. Com.*, Vol. 21, No. 1, 1942.

[2] "Simplified Subscribers' Telephone Sets," by E. S. McLarn, *Elec. Com.*, Vol. 21, No. 1, 1942.

simplified and more rugged construction should result in greatly decreased maintenance.

Inside Wire and Drop Wire

Inside wire and drop wire represent important elements of telephone systems. It is interesting to note that the I. T. & T. System pioneered in the development of No. 22 A.W.G. thermoplastic inside telephone wire as a substitute for No. 22 A.W.G. rubber covered and braided inside wire and has been using it for upwards of two years. The plastic insulated wire lasts longer, is better electrically, smaller, neater, and in normal times cheaper than the rubber covered and braided wire. Approximate normal demand, exclusive of Europe, is 11,000,000 feet of paired and 850,000 feet of triple inside wire.

Experiments are under way towards the adoption of plastic insulated parallel drop wire in place of rubber covered and braided parallel drop wire which is now the standard. Some six or seven years ago the I. T. & T. adopted Copperweld conductor for drop wire in place of bronze conductor. Copperweld conductor is 30% copper, whereas bronze conductor contains some 90% copper. I. T. & T. Operating Companies' consumption of drop wire, exclusive of Europe, is approximately 45,000,000 feet annually, so the saving in copper has been considerable.

Conservation of Critical Materials

Prior to production for defense, antedating the U. S. A. war production effort, the I. T. & T. System was alert to the advantages to be gained from material substitutions. Examples are the above mentioned modifications in inside wire and drop wire practice involving important copper and some rubber savings, and the substitution of cellulose acetate sheet, plastics and plastic sheathed cords for paper, fibre and silk insulation.

As the need for critical material conservation became essential to the war effort, studies involving substitutions of material were intensified. For die castings, which represented a major use of aluminum, zinc was substituted. In certain cases where used in sheet form zinc, in turn, was replaced by fibre. Aluminum has been generally replaced by substitutes such as phenol fibre sheet, thin sheet iron, etc., with the exception of aluminum foil for condensers for which no substitute is available.

Small sized lead covered cables formerly used in interior distribution work are being replaced by types not employing a lead covering. The possibility of utilizing smaller gauge conductors in lead covered cables is being studied; if successful, lead and copper requirements will be considerably reduced.

Tin is being conserved by radical reduction of its content in both wiping and bar solder. Further, by means of a new method of splicing lead covered cables, tin requirements are being greatly reduced. Tin coating of copper wire has been eliminated wherever possible.

Silk had been largely replaced by cellulose acetate yarns, such as Cotopa [3] for the insulation of central office equipment. Nylon is now being used extensively to replace natural silk in the insulation of fine magnet wires.

The I. T. & T. group of companies possess a background of experience in the export market extending over many years. In handling large equipment orders for shipment abroad, the International Standard Electrical Corporation, in particular, has engineered them with special reference to critical material conservation. Much has been accomplished in this direction, not only because of intimate knowledge of requirements and conditions prevailing in communication systems throughout the world, but also because of familiarity with local manufacturing conditions in many countries, thus making possible arrangements for local manufacture of parts and components and restricting U. S. A. shipments to minimum essentials.

I. T. & T. Operating Companies

TELEPHONE

During the year I. T. & T. Operating Telephone Companies showed a gain of 60,751 stations, or approximately 6 per cent. While this growth was made possible by decreasing the normal margin of spare facilities, it actually represented less than 50 per cent of the demand for additional service.

An additional intercontinental land line circuit between Buenos Aires, Argentina, and Santiago, Chile, was placed in service. In Mexico, toll line facilities were added between Mexico City and

[3] "Recent Developments in Esterified Fibrous Insulants," by A. A. New, *Elec. Com.*, Vol. 19, No. 2.

the U. S. A. border. Direct circuits also were provided between Monterrey and Matamoros, thus making it unnecessary to route toll calls through American territory between Matamoros and other Mexican points.

Communication facilities in several Western Hemisphere countries required for military and naval bases, together with interconnecting toll networks, were rushed to completion.

I. T. & T. Companies in Mexico, Peru and other countries, in normal times, were supplied with Rotary automatic equipment from Belgium and France; this source of supply of course ceased after Axis occupations of European countries. Similarly, Standard Telephone & Cables, London, supplied step-by-step automatic equipment to I. T. & T. Companies operating in Brazil, Argentina and Chile. S. T. & C. output since the war started naturally has been diverted to the armed forces, and material available from this source for companies in South America has been greatly restricted. To compensate for this loss of supply, the I. T. & T. established a factory in Newark, New Jersey, U. S. A., for the manufacture of equipment required by telephone subsidiaries and other customers in the Western Hemisphere. Here again, after the United States was forced into the war, this factory [4] became busily engaged in the manufacture of important combat and allied equipment.

Despite imposed restrictions of growth, material conservation and ingenious methods of improvization in general have enabled I. T. & T. Companies to meet essential service demands.

The telephone cord, indispensable at subscribers' stations and requiring frequent replacement due to wear and tear, serves as an interesting example of procedures adopted. Worn out cords are being replaced by shorter cords, thus effecting considerable savings in cordage consumption. Moreover, cords now are being maintained in service regardless of mere deterioration in appearance, and frayed or discolored cords are being reconditioned by covering them with new braid purchased locally. Other types of cords are given similar treatment so that the need for new cords has been reduced to the practical minimum.

A process has been developed for straightening bent switchboard plugs and also slightly enlarging the "ring," thereby extending the service life of a substantial quantity of plugs which otherwise would be fit only for the scrap heap.

Worn out switchboard jacks are being restored to standard size by cutting a longitudinal slot, compressing the sleeve of the jack, and soldering the slot.

Discolored telephone receiver casings and caps are being polished and reused; broken bakelite piece parts are being repaired with a cement which the various companies are able to procure locally. An interesting departure in the production of receiver and transmitter caps is making them of wood.

Previously abandoned drop wire is being recovered in large quantities and the practice has been instituted of salvaging subscribers' station drop wire whenever a station is removed from service, the wire being returned to the storeroom where it is graded and renovated wherever possible. Usable wire then is spliced into normal size coils and reissued to the installation forces. Some wire requires only minor repair, such as taping small abrasions in the braiding. Other wire requires complete over-hauling, which is accomplished by repairing defective portions of the rubber insulation and then rebraiding the wire.

In this and many other ways, I. T. & T. Operating Telephone Companies are maintaining the established tradition of the telephone industry that calls "must go through" despite obstacles—even those imposed by a global war.

Radio

The Buenos Aires-New York twin-channel, single sideband radio telephone link inaugurated in December, 1940, was greatly improved in 1942 and an entirely new type of secrecy equipment added. Consequently, two separate telephone conversations (one on each sideband) can be carried on simultaneously over this radio link with assurance of secrecy equal to that attained in wire transmission.

Similar twin-channel equipment has been delivered to Rio de Janeiro, Brazil, and to San Juan, Puerto Rico, and is now being installed in both locations. In Rio de Janeiro, the twin-channel receiving equipment is in operation and

[4] The Telephone Division of the Federal Telephone and Radio Corporation.

the terminal equipment and transmitter should be in service shortly. The Puerto Rican equipment will provide the first direct radio telephone circuit between San Juan and New York City.

In Brazil, international telephone facilities were installed in Recife and Natal; they should be in operation shortly. Sites have been purchased and similar equipment shipped for use at Sao Salvador (Bahia) and Belem. Additional expansion is contemplated.

In Peru, international telephone circuits were extended to the Republics of Venezuela and Colombia.

In Bogota, Colombia, new privacy equipment was installed and the international circuit to Buenos Aires and other points has been greatly improved.

In South America, the extension of radio telegraph services is under study and a number of important links have been opened. These include Caracas (Venezuela)—Buenos Aires (Argentina) and Asuncion (Paraguay)—Rio de Janeiro (Brazil).

In Puerto Rico, emergency radio telegraph equipment was installed for All America Cables and Radio, Inc., on the site of the Radio Corporation of Puerto Rico, a subsidiary of I. T. & T. This equipment will serve as an emergency alternate facility.

The Mackay Radio and Telegraph Company, as indicated below, has opened 18 new direct radio telegraph circuits since the entry of the U. S. A. into the war; eleven of these circuits were established in 1942.

Numerous changes have been effected in Mackay Radio plant facilities throughout the United States to provide services required by the military departments of the Government.

Two 50-KW International Short Wave Broadcasters

The two CBS 50-KW Intermediate Short Wave Broadcasters, built by the Federal Telephone and Radio Corporation, inaugurated last year, and described in this issue of *Electrical Communication*, now have completed over a year of continuous service in the dissemination of information and entertainment to the entire world. The design features incorporated in these transmitters, whereby programs can be transferred rapidly to any predetermined frequency and antenna array, are proving highly useful in the effective transmission of program material originated by the Columbia Broadcasting System and the Office of War Information.

Intermediate and High Frequency Marine Radio Units

While the Federal Telephone and Radio Corporation is a large producer of war matériel, both radio and telephone, the U. S. Maritime Commission in December, 1942, gave specific recognition to Federal through the award of the "M" Pennant and Victory Fleet Flag for the initiation, proposal and development of "the idea of a single unit for the radio room on the Liberty type vessels which contained all the radio equip-

December 15, 1941	New York–Kouibychev (Russia) and New York–Moscow
December 31, 1941	Honolulu–Chungking (China)
February 6, 1942	Honolulu–Chengtu (China)
February 15, 1942	San Francisco (California)–Kharbarovsk (Russia)
February 25, 1942	New York (New York)–LaPaz (Bolivia)
March 14, 1942	San Francisco (California)–Wellington (New Zealand)
March 25, 1942	New York (New York)–Asuncion (Paraguay)
April 12, 1942	San Francisco (California)–Sydney, Melbourne and Brisbane (Australia)
May 16, 1942	New York (New York)–Cairo (Egypt)
May 18, 1942	San Francisco (California)–Chungking (China)
July 2, 1942	New York (New York)–Bogota [5] (Colombia)
August 10, 1942	New York (New York)–Hamilton (Bermuda)
October 13, 1942	San Francisco (California)–Kunming (China)
February 1, 1943	New York (New York)–London (England)
March 1, 1943	New York (New York)–Algiers (North Africa)

[5] Government Station.

ment required by law." Adoption of this combination intermediate frequency unit, known as the Marine Radio Unit,[6] on Liberty type ships reduces installation time to a fraction of that formerly required and releases skilled labor for other war work.

A companion of the above unit, known as the High Frequency Marine Radio Unit and described in this issue of *Electrical Communication*, was developed in 1942. The new unit, within a single framework, contains a high frequency marine transmitter covering a frequency range of 2 mc to 24 mc, a motor generator power supply, a high frequency communication receiver, and all other facilities involved in a high frequency ship communication station. Like the intermediate frequency unit, the high frequency unit is supplied to ships completely wired, adjusted and ready for connection to the antenna and power lines.

Instrument Landing System

A complete two-course airplane Instrument Landing System, manufactured and installed for the Civil Aeronautics Administration by the Federal Telephone and Radio Corporation, was demonstrated at the New York Municipal Airport, December 2, 1942. The demonstration marked the culmination of several years of development jointly by C. A. A. and F. T. R. engineers at the Civil Aeronautics Administration Experimental Station located at Municipal Airport, Indianapolis, Indiana.

The system provides complete radio facilities for instrument landing at an airport. It makes landings possible with weather ceilings considerably below the present established minima without relaxing safety, which has always been the C. A. A.'s foremost consideration in supervising air transport operations. Eventually the new system will be installed at principal airports throughout the country to expedite schedules and increase their reliability by minimizing delays due to unfavorable weather.

Ultra High Frequency Two Course Radio Range with Sector Identification

On January 14, 1942, A. Alford and A. G. Kandoian presented a paper [7] before the Institute of Radio Engineers describing this U. H. F. radio range. Unlike previous ranges, the Ultra High Frequency Range is virtually free from atmospheric noise; hence, the service provided is uniformly good at all times.

A second major improvement results from the Sector Identification feature. With former radio ranges of the A and N or ·– and –· type, the pilot is unable to determine his position with respect to the radio range station from information conveyed by the radio range signal. For example, he receives the same signal regardless of whether the radio range station is ahead on the left or behind on the right—a serious deficiency and one requiring special flight procedure in order to determine the position of the plane with reference to the radio range station. The new type of range completely overcomes this difficulty inasmuch as the received signal not only provides information as to the plane's location with respect to the course, i.e., whether north or south of an east-west course, but also whether the plane is on the east or west side of the radio range station. This is accomplished by an aural signal.

A third important improvement is achieved by providing a visual pointer indication, which is generally more reliable than the aural A (·–) and N (–·) signal obtained with other ranges. The radio range is thus tied up with the Instrument Landing Systems which operate with the same pointer indication. Further, opportunity is provided for future application of the visual indicator signal to a gyro pilot which then would be able to keep the plane on a desired radio range course automatically.

In addition, as in the case of the conventional low frequency A and N aural radio ranges, the Two Course Radio Range with Sector Identification employs simultaneous voice modulation so that instruction, weather information, etc., may be conveyed to the pilot from the radio range station throughout his flight.

The development of this range covered a period of three years. It was completed in 1942 with the addition of the simultaneous voice feature.

Quartz Crystals

Plans by Federal Telephone and Radio Corporation for entering the field of crystal manufacture were formulated in October 1941 and

[6] "A New Marine Radio Unit for Cargo Vessels," by E. J. Girard, *Elec. Com.*, Vol. 20, No. 2.
[7] This paper has not been published.—EDITOR.

greatly accelerated after December 7, 1941, in connection with the war program. Training of employees started in June 1942, and, by the end of the month, deliveries commenced.

Shipments in December 1942 and subsequent months have about doubled each month and expectations are that the total volume for 1943 will be large. Considering the intricacies of Crystal production, change in type manufactured, man power shortage, and difficulties in procuring equipment, achievements to date and in prospect are recognized as outstanding by those familiar with the art.

Wire Transmission

The Wire Transmission Division of the Federal Telephone and Radio Corporation was organized early in 1942 and is engaged in the development and manufacture of telephone repeaters, toll line ringer-oscillators and other voice and carrier frequency transmission apparatus. Its activities are being devoted solely to war work for the United States Army and the United Nations.

Insulated Wire and Cables

Early in 1942 the "Intelin" Division of the Federal Telephone and Radio Corporation was formed to carry out research, development and manufacture of insulated wires and cables for telephone, carrier, radio and radar uses.

Due to the shortage of critical raw materials, considerable attention has been given to the development of synthetic dielectrics and rubber substitutes. The Intelin Division has developed over 600 types of dielectric materials and is manufacturing over 40 different types of high frequency and radar cables, which are urgently needed in modern combat equipment.

The progress made in these developments has been rapid and has resulted in considerable advances in the cable field. Not only has the frequency range been greatly extended, but modern technique makes possible the use of high power at these frequencies.

Along with mass production of the cables developed by the Intelin Division, intensive research and development continues in order to increase the practical application of other developments which are being carried out in the radio field.

As all of this work has been done quite rapidly, accelerated life tests are carried out in the field under operating conditions felt to be more severe than any which will actually be encountered so as to incorporate in the cable designs any features which will increase the factor of safety and thus increase the effectiveness of the combat equipment.

Because of accelerated accomplishments necessary to meet the emergency conditions, the probabilities are that there will be immediate peacetime applications for the synthetic dielectrics upon the cessation of hostilities.

Thin Case Hardening with Megacycle Energy

Federal Telephone and Radio Corporation's Industrial Electronics Division perfected a method of hardening a thin skin on steel parts without destroying valuable toughness beneath the surface using radio frequencies as high as 15,000,000 cycles. By restricting heat to the significant portion of the work, lower unit cost and increased production become possible. The method provides freedom from distortion or warpage and, together with freedom from scaling, makes final machining prior to heat treat feasible.

Vacuum tube oscillators for the new case hardening process are similar to high frequency radio transmitters and range in power up to 200 kilowatts. Space requirements of the equipment on the factory floor are small, however, since power supplies can be located at a remote point. The small space requirement plus the high production rate of the short heat cycle, a matter of a fraction of a second, makes radio frequency heat treatment an "in the line" production process.

Many parts of nominal size can be processed in automatic loading, heat treating, and ejection machines.

The new process is proving valuable in speeding the production of precision parts for the war effort.

I. T. & T. Selenium Rectifiers

The year under review witnessed a continued increase in the popularity of I. T. & T. Selenium Rectifiers for applications ranging from sizes suitable for miniature power supplies for portable equipment to stationary installations involving thousands of amperes. Applications of the rectifier are as may be expected—all for the war effort, including both actual items of war material and facilities for producing them.

Greater advantage is being taken of the ability of the Selenium Rectifier to operate reliably over a wide range of temperatures and rarified atmospheres as well as to withstand shock and vibration on warships, airplanes, and other fighting units. Moreover, their small copper content and the relative freedom from other critical materials make them particularly desirable over other equipment for rectifying alternating current.

A new small size rectifier plate, fitting into a tube and only a little larger in diameter than a lead pencil, is now available. It is finding many uses where small current rectifiers are required.

To improve operation and decrease weight for certain applications, a Selenium Rectifier plate which will operate at nearly double the reverse voltage of the present plate is now being manufactured.

During the past year complete equipment incorporating Selenium Rectifiers has been produced in much greater volume than heretofore. In addition to the more common uses, such as in storage battery charging and furnishing direct current for electroplating, communication systems and control equipment, many specialized adaptations have been evolved.

Specially interesting, due to their size and novel construction features, are Selenium Rectifiers being built to supply direct current for the electrolytic method of tin deposition. The electrolytic deposition of tin on strip steel had been slowly developing during the five year pre-war period. When the enemy succeeded in cutting off the United States from 80% of the world's tin supply, it immediately became apparent that some drastic measures would be required to conserve meagre tin stocks on hand. With the electrolytic method, it is possible to control the thickness of the coating and, especially for dry pack articles, to use only one-third of the amount of tin required by other methods of deposition.

The process is continuous with the strip operating at from 250 to 650 feet per minute. Expectations are that 1000 feet per minute will be practical within the next few months. At speeds of 650 feet per minute, each line requires approximately 48,000 to 60,000 amperes D.C. in order to produce a plate of suitable thickness.

About 26 of these continuous strip mills are being installed as part of the tin conservation program, and it is gratifying to note that F. T. & R. has been selected to furnish the D.C. conversion apparatus in the form of Selenium Rectifiers for 9 of these lines. The equipment being built consists of 18–7500 ampere units, 3–5000 ampere units and 3–3000 ampere units, making a total of 159,000 amperes at 12 volts D.C.

Selenium Rectifiers were selected for this application because of their efficiency, their small copper content compared with other means of converting of A.C. to D.C., and their freedom from maintenance. But probably the major consideration which led to the choice of Selenium Rectifiers was the fact that the units offered had the selenium plates immersed in a liquid which protects the plates from moisture and corrosive fumes as well as serving as a medium of heat transfer. This protection permits the location of the rectifiers near the plating tanks, thus further reducing the amount of copper necessary for the installation.

D.C. output voltage control is effected by means of saturable core reactors which are designed to provide voltage control from 0.75 volts to 12 volts.

Patents

Following a series of conferences arranged by the War Department in September, 1941, representatives of the radio industry unanimously adopted a resolution of far-reaching importance relative to patents. The resolution included a recommendation that the United States Government endeavor to obtain from owners of patent rights licenses in the fields of communication, signaling, remote control, navigation and direction and position indication.

The International Telephone and Telegraph Corporation and its subsidiaries, International Standard Electric Corporation and the Federal Telephone and Radio Corporation,[8] granted to the United States Government, for its own use or the use of any nation named by it, royalty free non-exclusive licenses under all of their United States patents and patent applica-

[8] Formerly the International Telephone & Radio Manufacturing Corporation and the Federal Telegraph Company, but since merged under the name, Federal Telephone and Radio Corporation.

tions for the duration of the war and six months thereafter. These licenses give the Government the free use of all inventions in the above mentioned fields.

Of the hundreds of patents and patent applications included in these licenses, a large percentage was based on inventions originated in the extensive laboratories of the International Telephone and Telegraph Corporation and its subsidiaries abroad. The majority of those derived from such sources were the result of intensive research and development work carried on by Standard Telephones and Cables, Ltd., London, Le Materiel Telephonique, Paris, and the Bell Telephone Manufacturing Company, Antwerp, over the past two decades.

Many of the inventions protected by these patents have proved their value by widespread use abroad in peacetime applications. Others are virtually limited to wartime use. Numbers of the inventions are secret. All are dedicated as a contribution of the International Telephone and Telegraph System to winning the war.

Federal Training School

In August, 1942, it became evident that the Federal Telephone and Radio Corporation would require skilled labor in excess of the visible supply. On the basis of a survey conducted under the direction of the Personnel Department, a training and upgrading program was started.

In some categories where the required skill is high, the training long, and the number of men required small, such as in the case of skilled glass blowers and first class structural workers, it was obviously necessary to continue hiring men in the general labor market. In other skills, such as in crystal matching and vacuum tube assembly, it was decided that the best way to train additional help was to place unskilled men directly on the production line under the supervision of foremen and their fellow workers, and let them learn by experience. It was apparent, however, that in many skills, such as wiring and assembly soldering, the number of additional people required was sufficient to justify setting up a separate training school where new workers could acquire the necessary facility before undertaking production work.

The school began operation on September 21, 1942, in conjunction with the Essex County Vocational High School War Production Training Program. Instructors are supplied by the Vocational System while classrooms and materials are supplied by the Federal Corporation. Students are employed by the Federal Personnel Department and are paid the regular rate for unskilled labor during the training period.

Two schools actually are maintained: one for assembly soldering and wiremen, and the other for radio testers, assembly, shop science and relay adjusting. Courses are of several types. Some courses, such as for assembler-solderers, wiremen Class 3, and radio testers Class 3, are of two weeks duration designed to give completely unskilled individuals an introductory knowledge of their future jobs. Other courses, of the upgrading type, give men and women already employed by the company the additional training necessary to fill jobs on a higher level. Advanced courses in radio test assembly and wiring are of this type and range in length from four to twelve weeks. Courses such as Methods Engineering and Foreman Training, designed to give foremen and other supervisory personnel a better grasp of manufacturing methods and employee problems, are held in the evening once or twice a week and last from two to ten weeks.

Army–Navy "E"

Awarded to

Federal
Telephone and Radio Laboratories

The Laboratories Division of the Federal Telephone and Radio Corporation, for great accomplishment in the production of war equipment, has been awarded the Army–Navy "E". The Army–Navy "E" Pennant and Employee Pins were presented at ceremonies held in the I. T. & T. Building, New York, N. Y. on April 20, 1943. Previously, the Maritime "M" Pennant and Victory Fleet Flag were awarded to the Radio Division of the Federal Telephone and Radio Corporation by the United States Maritime Commission for the initiation, proposal, development and production of the idea of a single unit for the radio room on the Liberty type vessels, containing all the radio equipment required by law.

The H. F. Marine Radio Unit

Newly Adopted Equipment Influencing Ship Design

By E. J. GIRARD

Federal Telephone and Radio Corporation, Newark, New Jersey

Editor's Note:

The materialization of the Intermediate Frequency Marine Radio Unit[1] *by the Federal Telephone and Radio Corporation, combining twelve separate pieces of apparatus in a single cabinet, is playing its part in accelerating the outfitting of Liberty type cargo vessels. In addition to compactness and simplicity of installation analogous to the plugging in of a home refrigerator or radio receiver, thus dispensing with time consuming processes involving decisions as to location of radio equipment and the making up of cables by skilled electricians to suit each particular case, the new unit lends itself to standardization on shipboard and greatly simplifies operating and maintenance problems. It is felt therefore that description of a companion unit—the H. F. Marine Radio Unit, possessing advantages comparable with the intermediate frequency unit—will be of interest to readers of* ELECTRICAL COMMUNICATION.

THE Marine Radio Unit, conceived and developed by the Federal Telephone and Radio Corporation, has substantially effected shipbuilding, operators' training, operation and maintenance of ship radio equipment. This was officially recognized by the U. S. Maritime Commission through its award to the Radio Division of F. T. & R. of the "M" Pennant, Victory Fleet Flag and Merit Badges.

Another original conception of the Federal Telephone and Radio Corporation, now being adopted by ship architects in the U. S. A., is the Marine High Frequency Unit—an entirely self-contained, complete high frequency ship installation, including transmitter, receiver, and power equipment in a single housing with projecting shelf for operating purposes. In addition to providing a simple, flexible and effective way of supplying long distance communication facilities over a continuously variable frequency range of 2 to 24 megacycles to any ship, it possesses advantages as regards installation, training, operating and servicing comparable with the Marine Radio Unit.

The development of the Marine Radio Unit and the Marine High Frequency Unit enables ship designers and Marine architects to determine well in advance the exact space requirements needed for a complete modern radio room installation, including both medium and high frequency. As a result of the invariable dimensions of the two types of units and consequent uniformity of installations, adequate but not excessive space can be provided in advance for ships' radio rooms. Waste of valuable capacity in the ships' structures can thus be avoided; the new units, in fact, are already influencing the design of ships' radio rooms.

New High Frequency Unit

For the High Frequency Unit the cabinet is of the same height and depth as the standard medium frequency Marine Radio Unit so that both may be installed side-by-side as companion units. When operated in conjunction with the regular Marine Radio Unit, power for high frequency operation may be obtained from the low frequency transmitter's motor generator supply so that no motor generator need be included with the High Frequency Unit. The keying relays of both transmitters are then wired together and the high frequency transmitter may be keyed from the low frequency desk panel.

Fig. 1 shows the new unit. The transmitter section occupies the upper portion of the cabinet with the receiver located in the center section

[1] "A New Marine Radio Unit for Cargo Vessels," by E. J. Girard, *Electrical Communication*, Vol. 20, No. 2, 1941.

directly above the desk panel or shelf. A motor generator to provide high voltage d-c as well as a-c for the filament transformer is located in the bottom compartment.

In line with its modern design and conception, the transmitter embodies a number of features which contribute to overall efficiency, usefulness and ease of operation. Although all the features are essential to a well-coordinated unit, one that stands out for wartime operation is the ability of the transmitter to be tuned continuously over its entire 2 to 24 megacycle range. Changeover to frequencies not ordinarily included in commercial ship frequency bands may be effected to make detection of transmitted signals by hostile forces difficult. Likewise, location of the transmitter with a location finder also becomes difficult. Continuous tuning is, of course, accomplished through use of a self-excited oscillator. The oscillator tuning range is divided into eight bands with ample overlap. A micrometer-type precision dial makes it possible to duplicate any frequency setting with great accuracy.

Ten crystals provided in the transmitter permit operation on 40 crystal-controlled frequencies. Fundamental oscillator frequencies of the crystals are from 1 to 2 megacycles and the resulting output frequencies from 2 to 24 megacycles are obtained through multiplying stages. Frequency stability with the self-excited oscillator exceeds 0.05 percent while, with crystal operation, it is better than 0.02 percent.

Circuit Features

Two 813 beam-power tetrodes in parallel in the power amplifier circuit provide a minimum RF output of 200 watts in the range of 2 to 16 megacycles when operated into a ship's normal antenna. Output of 150 watts is realized between 16 and 24 megacycles. Special antennas are not required for obtaining these outputs inasmuch as a matching network is employed for antenna tuning, permitting operation at any frequency into a wide variety of radiators. Consequently, the antenna used with the ship's intermediate frequency transmitter will operate satisfactorily with the high frequency equipment.

Beam power tubes, employed in all but the oscillating circuit, eliminate neutralizing. The oscillator is a 76 triode. Four 6L6 tetrodes link the oscillator to the power amplifier, the first connected as an isolating buffer and the remaining three as frequency multipliers. Four output frequencies from each oscillator frequency are obtained by combination of the multiplier stages.

Fig. 1—High Frequency Marine Radio Unit.

A special feature of the circuit is the method of connecting the power amplifier and the multiplier tubes in cascade, i.e., the current first flows through the power amplifier tubes and a regulating resistor. Current flowing in the power amplifier stage, therefore, controls potential applied to the multiplier plates and screens. The circuit further provides against high frequency voltages in the power amplifier plate circuit that would otherwise occur should the antenna circuit be detuned or opened; decreasing current in the power amplifier plate circuit, when the load is removed, results in an immediate decrease in grid drive so that current flowing in the driver stages as well as the power amplifier stages is reduced to low values.

Power Supplies

When the transmitter operates from its own power supply, the power source from the ship's mains may be either 115 or 230 volts d-c. Two types of motor generators can be supplied. Installations providing continuous wave emission only are equipped with a motor generator capable of supplying 1750 volts d-c at 0.4 amperes for the plate circuits and 78 volts a-c at 120 cycles for operating the tube filaments. The alternating circuit is obtained from slip rings on a d-c motor. For CW-MCW (A2) installations, a second type of motor generator provides, in addition to the above outputs, 200 volts at 700 cycles for plate modulation. The motor starter for both types of rotating units consists of an escapement type of time starter with suitable starting resistance to bring the motor up to speed without placing an excessive load on the d-c line. In addition, the starter is equipped with a pair of auxiliary contacts which function as a time delay of approximately 15 seconds to prevent keying until sufficient time has elapsed to permit the heater type tubes in the driver stages to assume operating temperatures. If power for the high frequency unit does not include 700 cycle a-c, a separate motor generator can be provided to supply a-c at this frequency for MCW operation.

Installation

Installation of the complete High Frequency Marine Radio Unit, when it is provided with its own power supply, is a simple matter of attaching the antenna lead to the post at the top of the unit and connection to the ship's power mains. The latter connection is made through a knockout at the rear of the unit. If the high frequency unit is to be operated in conjunction with a standard frequency Marine Radio Unit, suitable inter-connections are made between each unit so that power to operate the high frequency unit may be obtained from the standard frequency unit. A switch must be installed in the standard frequency unit to permit switching the power supply from low to high frequency operation. The keying relays are connected in series so that a single key serves for both.

Unit construction and easy accessibility of components characterize the design of the transmitter panel. Compactness and functional layout are illustrated in Fig. 2. The whole panel hinges at the bottom so that it can be dropped forward when in the cabinet, giving access to all tubes and components.

All frequency adjustments and operating controls are located on the front panel, eliminating the necessity of internal adjustments.

Conclusion

The new High Frequency Marine Radio Unit makes available complete long distance communication equipment employing the unit construction principle for shipboard radio installations. High frequency radio transmitting and receiving equipment supplements standard fre-

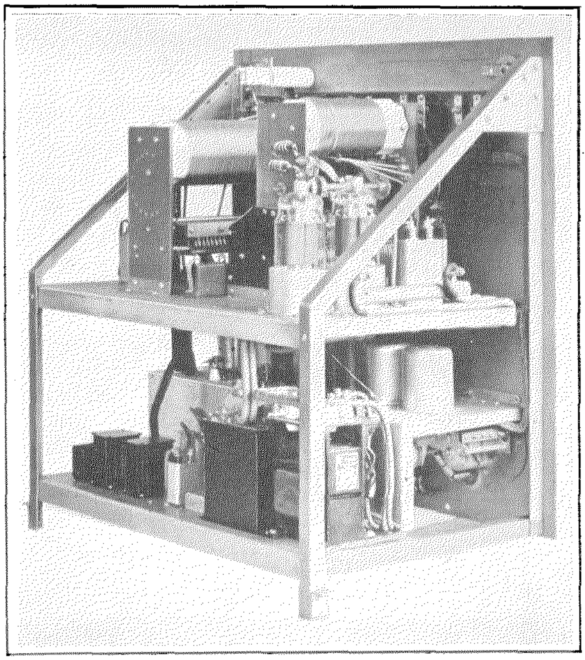


Fig. 2—Rear Left Side of Transmitter, Illustrating Compactness and Functional Layout.

quency installations on ships to permit, through choice of proper frequencies, means of direct communication with points far beyond the range of standard frequency working. Since long distance communication on high frequencies is accomplished with relatively low power, economy of operating the ship's radio is maintained even though the range is vastly extended. With elimination of ship-to-ship relaying of messages, accuracy and reliability are improved and communication with home ports is accelerated.

War has increased the number of long marine voyages with resultant great need for high frequency equipment. Ships located at the other side of the world must carry equipment capable of communication with their home ports directly since communication through land radio stations, land networks, and submarine cable is no longer readily available in certain areas. The indications are, too, that the post war period will impose similar requirements for long distance ship communications.

The ability to maintain secrecy through the practice of changing frequency at predetermined intervals makes the continuous tuning features in the High Frequency Marine Radio Unit quite valuable. Further, this same feature can also be useful in avoiding interference between stations by permitting operation just far enough off the frequency of an interfering station to prevent interruption of communications while staying in the same channel. With crystal operation, it might be necessary to switch to a less efficient channel to avoid interference.

Ease and simplicity of installation made possible through unit construction is now especially important in saving man hours and in speeding completion of ships for the war effort. As in the case of the assembly line, which has replaced older methods of manufacture, this new type of construction may well be the precursor of all future ship radio installations in view of its inherent economy and efficiency both from the viewpoint of installation and maintenance. Compactness, made possible by this unit construction, doubtless also will continue to appeal to ship designers.

As pointed out in connection with the intermediate frequency Marine Radio Unit, the unit method of construction standardizes the location of operated controls and thereby expedites and simplifies training of radio operators. This in effect means that regardless of where the equipment is installed, all controls are available to the operator in the same relative position. He is no longer confronted with the confusing problem of relearning the operating procedure on every new ship to which he may be assigned. With the extensive and more complex equipment in the modern radio room aboard ships, this factor becomes increasingly important. It is particularly so in high frequency installations where controls are more numerous and more critical.

Supervisory Remote Control for Wellington, New Zealand*

By E. M. S. McWHIRTER and H. J. WARD
Standard Telephones and Cables, Limited, London, England

ALL supervisory remote control systems have as their primary object the indication and control of switchgear and other plant used in the generation, transmission, and distribution of electricity when situated at an unattended sub-station and controlled from an attended station some distance away. The main urge towards remote control is not entirely the economic one of saving man power at the sub-stations, because it is now realized that if the modern complicated inter-connected network for power distribution is to be properly controlled, then there must be a central control room where the engineers can be instantly aware of everything that is taking place all over the network in order that no action of theirs at one point shall have deleterious reactions at another.

With such basic considerations in mind, and having regard to the distances often existing between the control point and the sub-station, it was natural that communication engineers should have turned their thoughts towards helping the power engineer to achieve his object by using a limited number of pilot lines. Prior to the war of 1914–18, remote control equipments had been installed in various parts of the world by power engineers, for the most part utilising one wire per unit (controlled or indicated). The relays employed were usually those associated with switchgear design rather than the smaller and lighter current relay familiar in automatic telephone switching. Such equipments were necessarily expensive, and to a degree inflexible, inasmuch as when all the pilot wires originally provided had been used, a further extension of the system involved the major expense of laying another multicore cable.

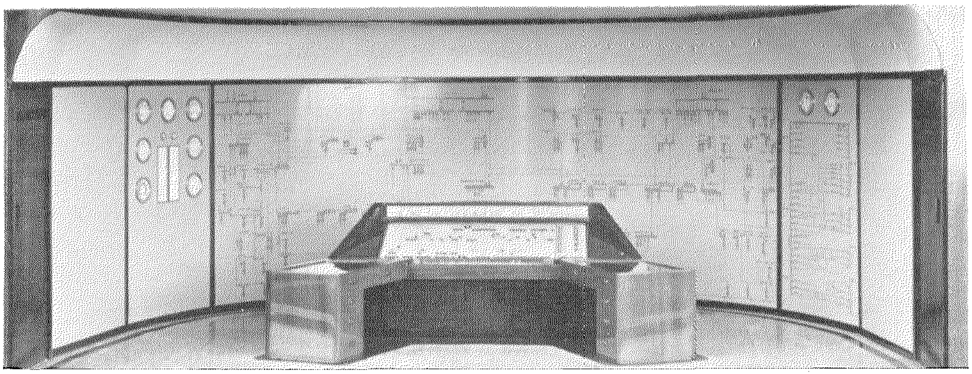
Progress in the Use of Automatic Telephone Apparatus

In the decade following the end of the last war, equipments were produced for the first time which enabled switchgear in remote sub-stations to be individually controlled over three or four telephone type pilot wires. Two such systems, designed by the Western Electric Company in the United States of America, had a comparatively wide application on the American Continent, and were manufactured by that company's London house for use in the British Isles and throughout various parts of the British Empire.

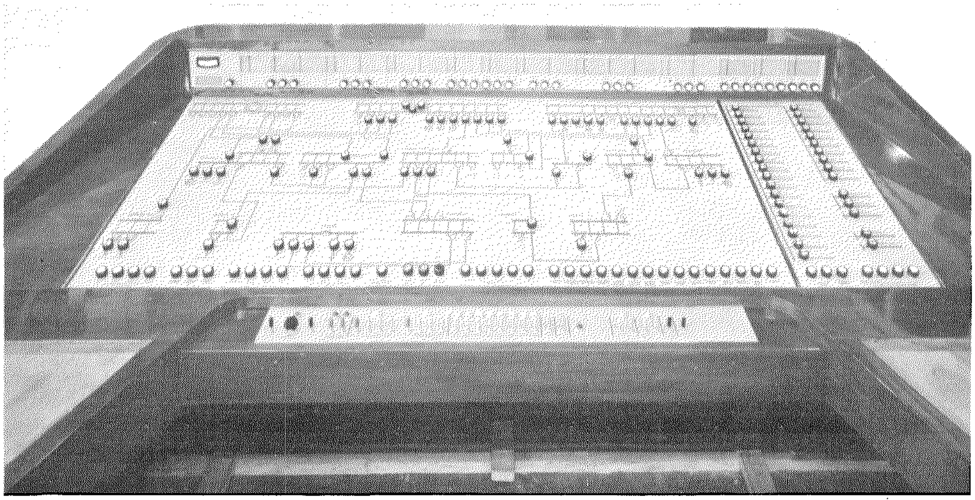
Of these two systems, one employing three-line wires, and based on the selection principle of the train-despatching selector and selector key, was intended to control a number of sub-stations connected in tandem through one set of pilot wires. The other system, employing four-line wires, was based on the principle of two synchronously rotating distributors, one at each end of the pilot, and was primarily intended for the remote control of a single large sub-station. With the rapid growth of supervisory remote control, it was soon found that the selection limitations inherent in these two systems militated against the power engineer's desire to extend the centralisation of his control to the full. Moreover, power engineers were beginning to be familiar with and confident of the possibilities of automatic telephone switching equipment, and it was natural that later equipments should tend towards employing the relays and switches that had become standardised in the sphere of automatic telephony.

During the period 1930–39 Standard Telephones and Cables, Ltd., designed and installed many important supervisory remote control installations throughout the British Empire, and in these the progress in economy of apparatus and in the expansion of facilities offered has been continuously maintained, culminating in the equipments supplied to the City of Wellington during 1939 for the complete centralised control of its electricity undertaking. It is not possible in the present short article to trace in detail this progress in design, but it will be as well to state briefly the facilities provided by the earlier types of equipment and to compare them with those

* Reprinted from *The Engineer*, Aug. 7, 1942.



Control Room



Control Desk Panel

now available, and so successfully applied to Wellington.

The earliest equipments using three or four-line wires enabled switches to be controlled and indicated. Remote indication of meters, if provided at all, was given by using a pair of pilot wires for each meter. Indication of the position of a remote switch was provided by red and green lamps, although it was later found necessary to introduce a third white lamp in order that the control operator could quickly determine which switch had changed position. The controller's equipment, then, consisted originally of rows of keys with their associated red and green lamps. Although later designs employed control diagrams, the control keys with their associated three lamps required so much space that diagrams for large equipments began to assume unwieldy proportions.

The equipment in use at Wellington is described in more detail later, but mention of the following facilities will serve to emphasise the progress which has been made in the application of automatic telephone apparatus to remote control. A number of sub-stations are controlled and indicated over one pair of pilot wires, whilst metering facilities are provided over other pilot wires to the more important stations. Continuous proving of pilot lines, and indication of sub-station alarms and of remote control supervisory alarms are also included, whilst any switch control circuit can be remotely transferred to a routine test circuit, enabling the whole switch control and indication operation to be tested without disturbing the switchgear position. All these facilities are controlled and indicated from one central control desk, a single combined key and lamp replacing the earlier two control keys and three lamps per switch. The indications are duplicated on a wall diagram in order to present a complete up-to-the-minute picture of the city network to the control engineer, whilst the miniature line diagram on the desk with the control keys inset therein enables him to study the more important switchgear interconnections.

Progress in the design of supervisory control equipment and the flexibility of modern equipment is well exemplified when it is realised that the contract for the Wellington City Council electricity department was carried through all stages of design and manufacture in London by Messrs. Preece, Cardew and Rider, consulting engineers, and Standard Telephones and Cables, Ltd., by correspondence only with the Wellington City Council engineers, and this despite the fact that the equipment had to operate switchgear already existing in Wellington and supplied by a number of different manufacturers and of a number of different types. That the equipment was so designed, manufactured, and shipped to site and installed by the electricity department's own engineers, with the co-operation of one Standard Telephones and Cables, Ltd., engineer from London, fully emphasises this feature.

Electricity Supply to the City of Wellington

Electrically, New Zealand, for her size and population, is among the best served countries in the world. Her water power has been developed during the last forty years by the public works department, and today hydro-electric stations feed the national networks which cover North Island and South Island alike.

The extent of the energy made available from the hydro-electric undertakings at Mangahao, Waikaremoana, and Arapuni is evidenced by the fact that, despite the use of electricity by farmer, manufacturer, and householder for every conceivable purpose, the steam plant of most of the cities of the Dominion is retained as stand-by equipment only, and Wellington is no exception to this rule. The capital city of the Dominion, it takes bulk power *viâ* the Government station at Khandallah from the hydro-electric station at Mangahao, supplementing this supply when necessary from the municipal generating station at Evans Bay.

Supply from these stations is taken to the main switching station at Jervois Quay, and from there a network of interconnected ring mains supplies power at 11 kV to twelve major sub-stations in the city area. From these major sub-stations are fed a number of minor sub-stations, from which power is distributed to the ultimate consumers. Certain of the major sub-stations also supply the city traction network through rotary converters at 550 volts D.C.

In planning the supervisory remote control system for their network, the city's engineers, with this grouping of sub-stations in mind, further classified the switchgear at the major sub-stations into three categories:—

Class (*a*)—Switchgear of primary importance to the 11-kV network, comprising generators, ring mains, bus-bar interconnectors, and the like.

Class (*b*)—Switchgear of minor importance to the 11-kV network.

Class (*c*)—Other switchgear.

It was decided that automatic mimic wall diagrams of the 11-kV and 550-V networks should be provided, whereon should be depicted in full the plant in the municipal generating station and the main switching station, such of the switchgear at the Government sub-station as concerned the city network, and the major sub-stations, together with their interconnections. In addition, the minor sub-stations were to be shown on these diagrams in their relative positions.

In depicting the three main stations and the twelve major sub-stations mentioned, the representation of Class (*a*) and Class (*b*) switchgear was to include automatic indication of the condition of these elements, whether closed or open, whilst the representation of the condition of Class (*c*) switchgear was to be effected manually on the diagram itself. As far as the minor sub-stations were concerned, an existing sub-station alarm system of Western Electric design, previously serving the major sub-stations and certain of the minor sub-stations, was to be diverted exclusively to serve these minor sub-stations.

A control desk was to be provided, including network diagrams similar to those mentioned above, but in skeleton form only. These diagrams were to include Class (*a*) switchgear and the system interconnections, together with such Class (*b*) switchgear as was necessary to make the diagram coherent. From this desk the control operator was to be given complete control facilities for his Class (*a*) switchgear. The representation of this gear on these diagrams was to be such as to enable him to initiate any required controls and to provide indication of the condition of the switchgear. The representation of the Class (*b*) switchgear was to be manual only, the position of the manual symbol giving the condition of the unit represented.

Remote Supervisory Control Equipment

The actual representation in the wall network diagrams of the Class (*a*) and Class (*b*) switchgear takes the form of magnetic semaphore indicators, each containing a lamp. The semaphore bars form part of the network diagram, and by their position relatively to the lines of the network indicate whether the switch units in question are open or closed, the lamp being automatically flashed to draw the control operator's attention to any change of position not originating from the control desk.

On the control desk Class (*a*) switchgear is represented by manual semaphore keys and Class (*b*) switchgear by manual semaphore symbols. The bars of these semaphore keys and symbols form part of the miniature network diagram, and by their position relative to it indicate whether the switchgear is closed or open. The semaphore keys enable the control operator to initiate the required controls, and each key contains a lamp. This lamp flashes automatically to call the control operator's attention to any change of condition not originated by himself and is further used as a pilot lamp when originating a control, being flashed rapidly to indicate that the circuit has been selected for control.

Class (*c*) switchgear is not included in the remote control system, and is represented on the wall diagrams only, where its representation takes the form of manual semaphore indicators pre-set by the control operator in accordance with the known condition of the switchgear. The minor sub-stations are represented on the wall diagram only, where for each there appears a single lamp which lights whenever a fault condition obtains at the sub-station. No indication, however, is given of the exact nature of such fault condition.

For the satisfactory operation of the system it is essential that the control operator should either be given continual information as to the loading of his network or that he should be able to obtain this information automatically when desired. His requirements do not fall entirely into either category, and certain information, therefore, is given continuously, while he may obtain other information by the operation of appropriate keys on the control desk. The automatic indications include:—

(*a*) The power intake from the Government station.

(*b*) The supply network voltage.

(*c*) The supply network frequency.

(*d*) The traction network voltage.

While the generating station at Evans Bay, permanently manned, naturally has indications (*b*) and (*c*) independently of the control operator, indication (*a*) is extended to them by the control operator for their information.

The indications which the control operator may obtain on request comprise:—

(*e*) The output from any one of four generators at Evans Bay.

(*f*) The voltage or current of any one of the four generators at Evans Bay.

(*g*) The current taken by any one of three rotary converters at the main switching station.

These indications are sufficient for the normal running of the system, but in an emergency the control operator is provided with the means of sectionalising his network rapidly and of synchronising and paralleling the two supplies should they have been disconnected from one another.

For sectionalising the network the control operator is provided with five keys on his control desk by the use of which he may cause the network to be sectionalised in any one of the five ways. Signals initiated from these keys are effective at all stations simultaneously, at each of which up to five simultaneous controls can thereby be effected.

For synchronising and paralleling the two supplies, the control operator is provided with:—

(*h*) Indication of the voltage of the incoming supply.

(*i*) Indication of the voltage of the running supply.

(*j*) Indication of the relative phase and frequency of the two supplies.

(*k*) Means for paralleling the two supplies immediately he is satisfied as to the correct phase, frequency, and voltage relationships between them.

It is essential that, in an emergency, contact shall not be lost between the control operator and the power station, and to this end normal telephonic intercommunication is supplemented by a series of routine instructions which the control operator may transmit *viâ* the supervisory gear to the generating station, where they are displayed visually on an indicator of the signal head type. Further, certain automatic indications of the condition of the steam and generating plants at the power station are automatically signalled to the control operator by the supervisory gear, so that he may know what machinery is immediately available, and what can shortly be brought into service. Another interesting feature of this system is that the Western Electric alarm system, previously mentioned, incorporated telephone facilities which have been included and extended in the supervisory control scheme.

Certain important new features have also been added. In order that a permanent record of any important conversation taking place between the control operator and the Public Works Department, power station, or any of the sub-stations on the network may be available for reference if necessary, a dictaphone recording system has been incorporated and may be brought into service at any moment by the depression of the key by the control operator. Further, to simplify his task in emergency, a loud-speaking telephone system has been added using voice-operated switching, which enables him to carry on conversation with the power station or the main switching station while carrying out controls from his desk.

An inspection of the accompanying illustrations of the control room and control desk panel reveals the network diagrams and the metering panels. The telephone equipment is controlled by the row of keys at the front of the desk, but additionally at the back of the desk will be seen a vertical panel. This is the "Alarm Discrimination Panel," whereon a section is allocated to each station or sub-station on the supervisory control system. Its function is primarily to direct the control operator's attention to the appropriate part of the network diagrams whenever an automatic trip occurs. In this event the legend "Breaker Change" in the section appropriate to the particular sub-station flashes slowly and continues to flash until the change has been "accepted." "Acceptance" takes two forms:— For Class (*a*) switchgear it is necessary to rotate the corresponding semaphore key on the desk into agreement with the new condition of the switchgear. For Class (*b*) switchgear no semaphore keys being provided, the "acceptance" is effected by the depression of a "Re-set" key on the alarm discrimination panel below the group of sub-stations in which the affected sub-station lies. It will be noted that there are nine such groups with a spare position for a tenth.

Also associated with each group of sub-stations are two other keys designated "Check" and "Test" respectively. The "Check" key enables the control operator to verify the indicated condition of the switchgear at the sub-stations within the group itself, its operation causing a signal to be sent to these sub-stations, which thereupon return a complete indication of the condition of every element of switchgear concerned. The request signal having been sent, the "On Check" legend lights on the alarm discrimination panel in the section corresponding to each sub-station in the group and remains alight until a complete check has been received.

The "Test" key enables the control operator to put the sub-stations in the group into an "On Test" condition, during which he may carry out his normal controls, receiving the corresponding indications of change without actually affecting the switchgear. The signal which puts the sub-station "On Test" disconnects the controls and indications from the actual switchgear, and transfers them to a dummy set which takes the form of mechanically latched relays. The transfer causes a signal to be returned from the sub-station to the control operator, causing "On Test" legends to light in the appropriate sections of the alarm discrimination panel. When the control operator has, by the use of this facility, thoroughly routined his supervisory system, the same "Test" key enables him to restore conditions to normal, whereupon a check of the group of sub-stations re-establishes his network diagrams to the true conditions, the "On Test" legend being extinguished.

Other legends appearing on the alarm discrimination panel are "Low Volts" and "Sub-station Fuse." These give indications of the state of the supervisory equipment at the sub-station so that the control operator may know when a fuse has blown or when the battery volts are falling, so that the maintenance staff can take appropriate action.

The requirements of speed and safety demand that as many indications as it is possible to send simultaneously should be given access to the control operator, but that he should normally be unable to effect more than one control at a time. This is the case with the present system. From each group of sub-stations one signal only may be received at a time, each such signal giving complete indication of seven elements of switchgear. Thus, while the control operator may normally effect only one control at a time, he may receive at present up to sixty-three simultaneous indications and up to seventy indications when the tenth group of sub-stations is brought into service.

Train Orders by Facsimile Telegraphy

By J. H. HACKENBERG, B.E.E. and G. H. RIDINGS, B.S.
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AMERICAN railroads are today moving a larger volume of traffic, both freight and passenger, than ever before in their history; and they are doing it with less rolling stock and less manpower than in the last war. This has been made possible by a far sighted policy of improvements that has resulted in the modernization of rolling stock, roadbed, signalling facilities, yards and terminals, and by the intelligent cooperation of all who use the railroads. This modernization program, which was pursued courageously through the depression years, is being continued through the present war boom so that month after month new record traffic levels are recorded and new peaks of efficiency attained.

This program has not been limited to the modernization of traffic handling plant, but has included new methods of pick-up and delivery, new car loading systems, new methods and materials for the maintenance of equipment, and new communication facilities. Facsimile telegraphy, the newest, most modern communication tool, is one of the devices recently called upon by the railroads to help them meet the unprecedented demands of today.

Facsimile telegraphy has many advantages over other forms of communication for several railroad applications. For example, facsimile's inherent accuracy makes it an ideal method for the handling of train orders. The possibility of human error is greatly reduced: once the order is prepared for transmission it need never again be manually copied. The possibility of transmission error is greatly reduced by facsimile's ability to operate through extremely high levels of interference. Simplicity of operation, and the ease with which duplicate copies may be secured, are additional advantages.

In American railroading, it is customary for the telegraph operators at the various stations along the route to deliver orders to the train crews. Such a system requires that the stations be spaced reasonably close together. Where the stations are a considerable distance apart, or where a number of the stations are closed, as at night, the distance between points at which orders may be given to the train crews may be many miles. To avoid unnecessarily long layovers and to maintain fast schedules, it is often necessary to deliver train orders to the crews at intervening points, some of which may be quite remote from a station at which an operator is on duty.

In such situations, facsimile telegraphy provides an ideal method of getting the orders to the train crews. Automatic recorders, housed in small shacks along the right-of-way, are located at sidings, branches, crossings—wherever a train might be required to stop. Recorders may also be installed in small stations, such as suburban commuting stations where telegraph service is not provided. An automatic transmitter, under control of the operator for the district, is arranged so that he may transmit orders to any of these recorders.

Since the recorders are entirely automatic, the order may be transmitted in advance of the arrival of the train so that it is waiting for the conductor when he arrives. The circuit is so arranged that the transmitter may be set by the operator to send automatically as many copies of the order as are required by the various members of the train crew. Thus the orders are secured by the train crew with a minimum of time and effort. The time and effort required of the operator are equally slight; he simply dials the desired recorder, sets an indicator to the desired number of copies, and drops the order into the machine. No further attention is required of him.

A recorder readily adapted to such service was developed by the Western Union Telegraph Company for use in conjunction with automatic transmitters similar to the Types 22 and 122 previously described in this journal.[1] This automatic telegraph recorder, which is known as Telefax

[1] "Facsimile Telegraphy, Some New Commercial Applications," by John H. Hackenberg, *Elec. Com.*, Vol. 18, No. 3, Jan., 1940, pp. 240–251.

Recorder Type 801, was designed for use in tie line service in branch offices and similar locations, where assistance to patrons at the counter and other duties must, at times, receive the clerk's undivided attention. This recorder and its associated transmitter, which is known as Telefax Transmitter Type 703, comprise what is probably the most completely automatic telegraph system yet devised. Messages are deposited into the transmitter in much the same manner as a letter is inserted into a mail box and with as little effort. The recorder requires no attention at all. The messages simply roll out of the machine into a receptacle, whether or not there is any one present to receive them.

The transmitter, housed in an attractive metal case and furnished with a matching pedestal, occupies a 12 in. x 16 in. floor space. In appearance it resembles a small vending machine. The transmitter is complete in itself, requiring only the line pair, a ground connection and a source of 110 volts 50–60 cycle A.C. power for its operation. Maximum power consumption is about 220 watts. Fig. 1 is a photograph of Telefax Transmitter Type 703.

Fig. 1—Telefax Transmitter Type 703.

Telefax Recorder Type 801 is housed in a metal case of the same general design as that employed with Transmitter 703, and is mounted on a pedestal which in this instance contains drawers in which are located portions of the receiving equipment. This arrangement facilitates maintenance in that all working parts are readily accessible and replaceable by units. The recorder requires a floor space of about 20 in. x 22 in., and is somewhat higher than the transmitter. It requires for its operation a source of 50–60 cycle 110 volt A.C. synchronous with that at the transmitter, in addition to the line pair and ground connection. Maximum power consumption when recording is about 400 watts. Fig. 2 is a photograph of this recorder with cover and drawers open to show some of the details.

A carrier frequency of 2500 cycles, a drum speed of 180 r.p.m. and a line advance of 1/100 inch per revolution are employed in this system. These constants, which have become standard in Western Union facsimile equipment, permit scanning the entire message blank in two minutes. Where desired and where circuit conditions permit, a carrier frequency of 5000 cycles and a drum speed of 360 r.p.m. may be employed, thus scanning the full blank in one minute.

The line circuit should be a reasonably quiet pair with a loss not exceeding 25 db at the carrier frequency. Over this circuit flows the facsimile tone signals, generated at the transmitter, and also the D.C. control currents. The control circuits operate on a ground return basis. A relay in one line wire at the recorder permits certain functions of the recorder to be controlled by the transmitter. A relay in the other line wire at the transmitter permits certain functions of the transmitter to be controlled by the recorder. These line relays are three-position polar relays, the position being controlled by the polarity of the D.C. potential applied at the other end of the circuit. If the potential is removed from the line the relay stands in the center position touching neither contact. The facsimile tone signals are applied and taken from the line pair through condensers which thus separate the A.C. and D.C. circuits.

In the basic design of this system, the transmitter is equipped with a push button for starting. The transmitting amplifier and a line amplifier at the recorder are connected to power at all times to avoid a delay while the amplifier tubes are heating up. A person wishing to send a message depresses the starting button on the front of the transmitter. In less than two seconds the chute opens and into it he deposits the message which has been prepared on the special blank for use with this transmitter. These operations are all that is required of him. When the starting button is depressed, power is applied to the transmitter and a facsimile tone is generated and sent over the line to the recorder. This tone energizes a relay in the output of the line amplifier at the recorder, connecting power to the balance of the recorder. When the recorder is ready to record, a D.C. potential is applied to one line of the pair operating the line relay at the transmitter, which in turn opens the message chute and illuminates a panel reading "DEPOSIT TELEGRAM." Thus in a two second period the circuit and equipment are actually tested before each message is sent, in fact before it is possible to deposit the message into the transmitter. The possibility of lost messages, due to line or equipment failures, is thereby virtually eliminated.

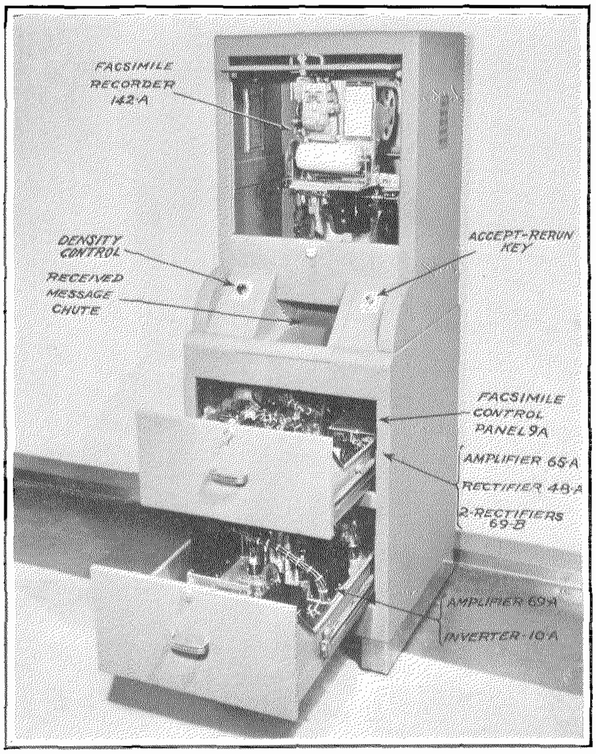

Fig. 2—Telefax Recorder Type 801.

The recorder employs Western Union's dry record sheet Teledeltos,[2] in rolls of cut blanks. These rolls consist of about four hundred 6 in. x $8\frac{3}{4}$ in. blanks, held in place by a long wide paper belt. In preparing these rolls the blanks are spaced on the belt so that they overlap each other by about an inch. This facilitates the feeding of the blank from the roll and into the proper position to be placed on the recorder drum. A roll of blanks is placed in the recorder and the paper belt fed over one roller and under another to a take-up reel, in much the same manner as a roll of film is placed in a camera. A small motor drives the take-up reel, slowly unwinding the paper belt and drawing with it a blank from the roll.

This blank is fed down through a chute to a pair of light leaf springs at the bottom of the chute which serve as a stop. On the same horizontal level with these springs are a small light bulb and a photocell, arranged so that the light which is focused onto the photocell is blocked when the leading edge of the blank reaches this level. At this point the blank is considered in the "phase" position. The photocell operates a relay which controls power to the motor driving the take-up reel. Thus, the instant a blank reaches the "phase" position, current to the motor is interrupted and the belt stops moving. Back contacts on this relay are in series with the source of D.C. potential which gives the "DEPOSIT TELEGRAM" signal to the transmitter and opens the message chute. The opening of the chute at the transmitter is therefore a guarantee that the recorder is ready.

When the message is dropped into the chute of the transmitter, it is guided immediately between an idler roller and the drum. The idler roller impales the message blank on a row of spiked projections, situated about the circumference of the drum, thus holding the blank snugly against the drum. In its passage onto the drum, the message blank operates contacts which extinguish the "DEPOSIT TELEGRAM" light and close the message chute. They also cause the half-nut to be held against the feed screw, starting scanning, and cause a D.C. potential to be applied to one wire of the line pair which operates the line relay at the recorder. This relay sets up a circuit which at the proper time acts to place a recording blank on the drum.

[2] See previous reference.

Printed just above the writing space on the special transmitting blank is a solid black square. This square, called the "phasing square," is the only mark scanned during the first few revolutions of the blank. As this phasing square is scanned on the first revolution of the drum after the blank is in place, the resultant momentary interruption of tone causes a relay at the recorder to be energized and to lock up. This relay in turn energizes a solenoid which acts to move an idler roller against the recorder drum. This idler roller, situated directly behind the recording blank resting in the "phase" position, impales the blank on a row of spiked projections on the circumference of the recorder drum in much the same manner as is done at the transmitter. It will be noted that while the circumferential position of the message blank on the transmitter drum is entirely haphazard, the position of the recording blank bears a definite unvarying phase relationship to the position of the transmitting blank because the impulse which places the recording blank on the drum originates from a fixed point on the transmitting blank.

In its passage onto the drum, the recording blank operates contacts which release (after a slight time delay) the solenoid holding the idler roller against the drum. These contacts also cause the half-nut to engage the feed screw and release the recording stylus, allowing it to rest on the rotating blank. After the recording blank is "phased" onto the recorder drum, and while the message is being recorded, the light bulb and photocell act to cause the paper feed motor to draw another blank from the roll and into position for the next message.

The recording of the message proceeds until the writing space on the transmitting blank has been scanned, at which time a contact is made by the movement of the transmitter carriage, which removes the D.C. potential from the line and releases the line relay at the recorder. Releasing this relay energizes the peel magnet, a magnet which has attached to its armature a flat spatula-shaped projection. This projection is drawn against the drum and slips under the leading edge of the recording blank as it rotates, stripping it from the spikes which hold it to the drum. The message is deposited into a receptacle at the front of the recorder. As the blank leaves the recorder drum it opens contacts which release the half-nut (permitting the recorder carriage to return to the starting position) and reverse the polarity of the D.C. potential applied to the line. This reversal of line potential at the recorder causes the line relay at the transmitter to release the half-nut (allowing the transmitter carriage to return to the starting position) and to operate

Fig. 3—Telefax Recorder Type 803.

the peel magnet stripping the message blank from the drum. The message blank is deposited into a receptacle at the bottom of the transmitter and the transmitter shuts down. Since tone is now removed from the line, after two or three seconds the recorder also shuts down.

A number of features are incorporated into this equipment to provide a maximum of efficiency and convenience in a wide variety of services. The transmitter is equipped with an "Intermittent-Continuous" switch which when thrown to "Continuous" keeps the transmitter running and causes the chute to be reopened after a message blank is peeled from the drum. This feature, which makes it unnecessary for the operator to press the start button for each message, is of value where the equipment is used in more or less continuous service. Another feature, designed to increase the capacity of the equipment when the volume of business is extremely heavy, is the "Long-Short Message" switch. This switch, which is operated for each short message, connects into the circuit a second set of end-of-message contacts which may be adjusted when the machine is installed to operate at any desired length of carriage travel. Where a large percentage of the messages handled are short, a considerable amount of time is saved by not scanning the unused bottom portion of the blank.

The recorder is equipped with an "Accept-Rerun" key which permits the recorder to be arranged for automatic acceptance of the recorded copies as described above, or for manual acceptance, and permits a recorder attendant to obtain additional copies if desired. A vernier level control is provided on the recorder by means of which the attendant may adjust the density of the recorded copy, making it darker or lighter as desired.

The equipment is equally efficient in intermittent and continuous services. When arranged for intermittent service only a minimum of "standby" power is required between messages. This, and the other features mentioned above, make this system adaptable to a wide variety of services, not only in the telegraph industry, but in other industries as well. With the few minor modifications which will now be described, it becomes an ideal system for the distribution of train orders.

Fig. 4—Telefax Transmitter Type 706.

In the distribution of train orders, it is desirable to have the single transmitter, which is operated by the telegraph operator, and the several recorders which are located at suitable points along the right-of-way, all connected by a single line pair. This is readily accomplished by the use of a selector cabinet with each recorder and a telephone type dial at the transmitter. The desired recorder is selected by dialing. In this arrangement the line amplifier of the recorder is not connected to power until the recorder is selected. A selector in the selector cabinet of the desired recorder, operated by D.C. over one wire of the line pair, connects standby power to that recorder, all other recorders remaining disconnected. As soon as the vacuum tubes of the line amplifier heat up, the recorder itself is turned on as usual by the facsimile tone from the transmitter.

An additional safety feature is incorporated in the selector cabinet. This consists of a motor driven code wheel actuated by the selector, which, by means of D.C. over the other wire of the line pair, operates a buzzer in the transmitter, assuring the operator that he is connected to the desired recorder. This answer-back code will not be given unless there is a blank in the "phase" position of the recorder. The answer-back code is an assurance not only of having selected the desired recorder, but also that the recorder is ready to operate.

Facilities are provided in the selector cabinet whereby an acknowledgment of the receipt of orders may be had if desired. This is accomplished in the following manner: The conductor (or other designated member of the train crew) upon picking up the order depresses a button which extends through the side of the selector cabinet. This causes the answer-back code to be altered by the insertion of a long dash prior to the code signal, so that the next time the operator at the transmitter dials this recorder he will know by the altered code that the order has been picked up. If the operator has dialed the recorder simply to determine if the previous order was picked up and has no order to be transmitted at this time, he turns off the transmitter causing the recorder to shut down, the selector to be released and the acknowledgment button to be restored to the unoperated position.

Since in the distribution of train orders the recorder is always arranged for automatic acceptance, the "Accept-Rerun" key is unnecessary and is omitted. Fig. 3 is a photograph of the recorder employed in this service which is known as Telefax Recorder Type 803.

The transmitter employed in the distribution of train orders is known as Telefax Transmitter

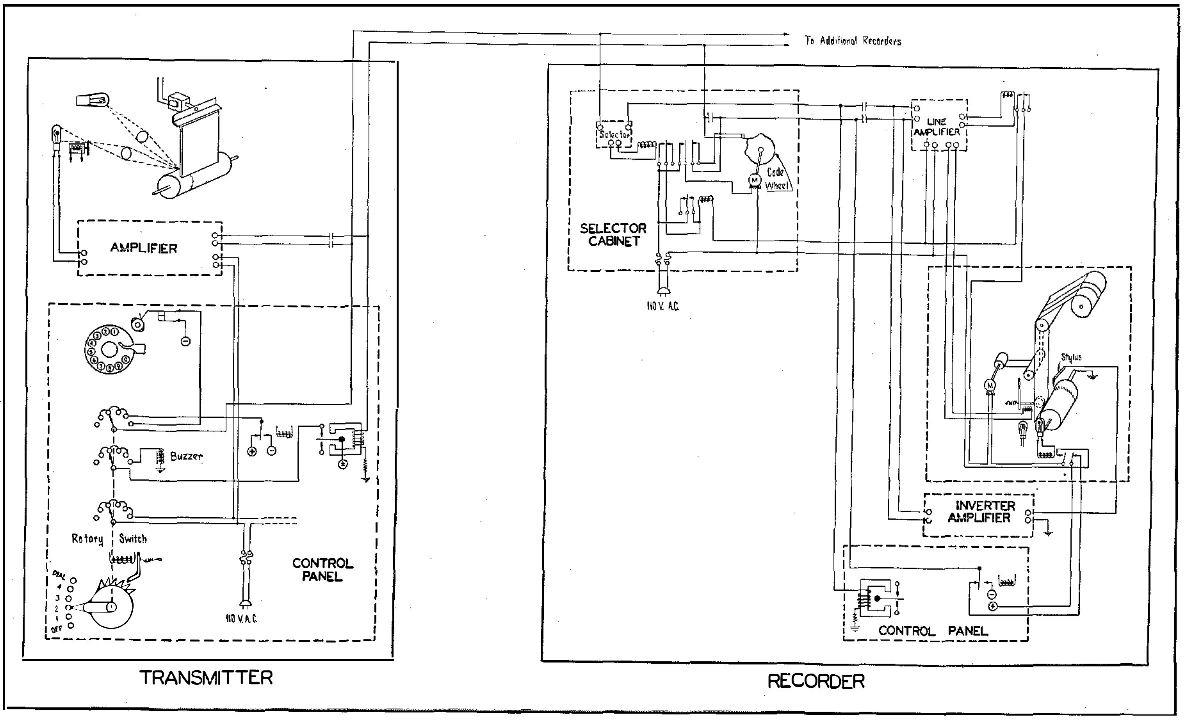

Fig. 5—Circuit Essentials Employed in Railroad Facsimile Service.

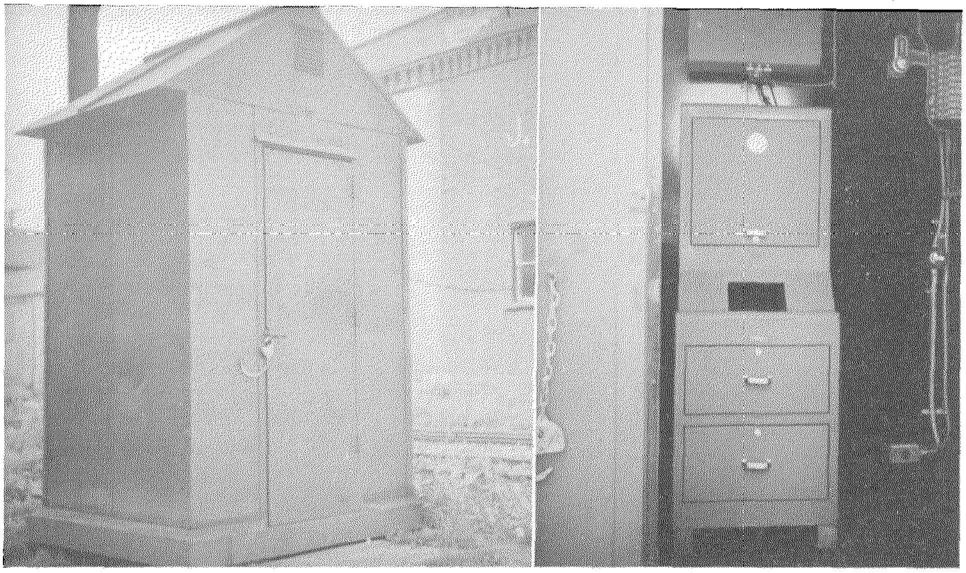

Fig. 6—Views of Typical Facsimile Recorder Installation.

Type 706. This transmitter, which is shown in Fig. 4, is provided with a small control panel conveniently located on the top of the machine. This control panel, which replaces the smaller control panel employed on the Type 703 Transmitter, contains the dial by means of which the desired recorder is selected and a six-position rotary stepping switch. By means of this switch the transmitter is made to send automatically the desired number of copies before shutting down. The positions of this switch are labeled OFF, 1, 2, 3, 4, DIAL. In operating the transmitter this switch is first turned to DIAL, starting the transmitter. As this switch replaces the start push button, and the "Intermittent-Continuous" switch, those items are omitted from this transmitter.

In the DIAL position a buzzer is connected into the circuit to receive the answer-back code signal from the dialed recorder. After dialing, about 20 seconds elapse before the answer-back signal is received, i.e., the time required for the amplifier tubes of the recorder to heat up. When this signal is received, the switch is then moved to the number corresponding to the number of copies of the train order it is desired to record. The buzzer is disconnected and the chute opens so that the operator may deposit the train order. As soon as the train order is deposited into the chute, the chute closes and the message is recorded, as already described. Since train orders are on standard forms of uniform length, the second set of end-of-message contacts and the "Long-Short Message" switch are unnecessary and are omitted from this transmitter.

In this circuit the reversal of the D.C. potential applied to the line at the recorder by the blank leaving the recorder drum at the end-of-message not only permits the transmitter carriage to return to its starting position, but also acts to step the rotary switch back one step. Instead of acting to strip the blank from the transmitter drum, this polarity reversal acts to apply to the other line wire at the transmitter that polarity which sets up the recorder for "phasing" another blank onto the drum. In this manner the train order is automatically rerun the desired number of times, the last step of the rotary switch causing the blank to be stripped from the transmitter drum and the transmitter to shut down. In a few seconds, lack of tone from the transmitter also causes the recorder to shut down. Lack of power being drawn by the recorder releases a relay in the selector cabinet and the circuit is released to await the next train order.

Fig. 5 is a schematic diagram showing the essentials of the circuit employed in this service. For the sake of simplicity, many details have been omitted. A positive modulated signal is transmitted over the line, just as produced by direct scanning of the subject copy. This "negative" is converted into a "positive" by means of an electronic inverter incorporated in the recorder.

Fig. 6 is a photograph of a typical recorder installation. The selector cabinet may be seen mounted on the wall above the recorder.

While it is still too early to fully appraise the results of the first few installations, it would appear from the reports that have been received that this equipment is definitely earning a place in the railroad industry. There are undoubtedly many other situations, not only in the railroad industry but also in other industries, where facsimile telegraphy may be made to serve the public and the nation.

A Machine for Calculating the Polar Diagram of an Antenna System

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Summary

The machine described below enables one to determine a polar diagram in a fraction of the time required by direct calculation. A computation which ordinarily would consume a whole day can be performed in 15 minutes on the machine. In its present version, it will calculate the polar diagram given by as many as five antennae. These may be situated anywhere within a circle of four wavelengths diameter, whilst the currents in the antennae may have any relative phases and magnitudes. The exploring angle is read off from a dial marked in degrees, whilst the corresponding relative amplitude is shown directly on a voltmeter. As few or as many readings as one likes can be taken, and also one may turn the handle backwards to a previous value if required.

With such a machine there is an appreciable reduction in the possibilities of errors, for once the machine is properly set up it is incapable of errors—a feature quite as important as the saving of time. It now also is practicable to consider a large number of variations in a design, the working out of which would take a prohibitive time without such a machine.

Although the number of antennae catered for in the present model is five, the principle of operation will allow for its extension to any number of antennae. Moreover, the system could readily be extended for tracing out the polar curve automatically. For this refinement all that is required is a turntable (which would be operated off the common main shaft) and a recording type voltmeter.

A view of the machine, which has been in constant service for about two years is shown in Fig. 1.

1. *Introduction*

Problems frequently arise nowadays involving the use of two or more antennae whose relative currents and positions are arranged in such a way as to produce some desired polar diagram of radiation from the antenna system as a whole. In many cases the antenna system consists of vertical radiators each one of which, when considered by itself, has a polar diagram which is a circle, i.e., the radiation in the horizontal plane is uniform in all directions. By varying the relative magnitudes and phases of the currents in each antenna, and also by varying the positions of the antennae in the horizontal plane, any number of different polar diagrams may be obtained.

The design of such directional antenna systems is required in problems of the following types:

(*a*) In the directing of radiation from a broadcast transmission. For example, it may be desirable to increase it in the direction in which the population is greatest (at the expense of a decrease in radiation in other directions);

(*b*) In point-to-point commercial communication systems;

(*c*) In keyed beam systems giving horizontal guidance to aircraft;

(*d*) In the setting up of a radiation pattern suitable for providing a glide path for aircraft.[1]

Calculating polar diagrams involving three or more antennae is a tedious business. Moreover, one is often faced with a problem in antenna design that may involve the plotting of some dozens of curves of which only a few are eventually found useful.

Considerations of this nature led the author to study the possibilities of performing such

[1] "The Development of the Civil Aeronautics Authority Instrument Landing System at Indianapolis," by W. E. Jackson, A. Alford, P. F. Byrne and H. B. Fischer, *Electrical Communication,* Volume 18, No. 4, April 1940.

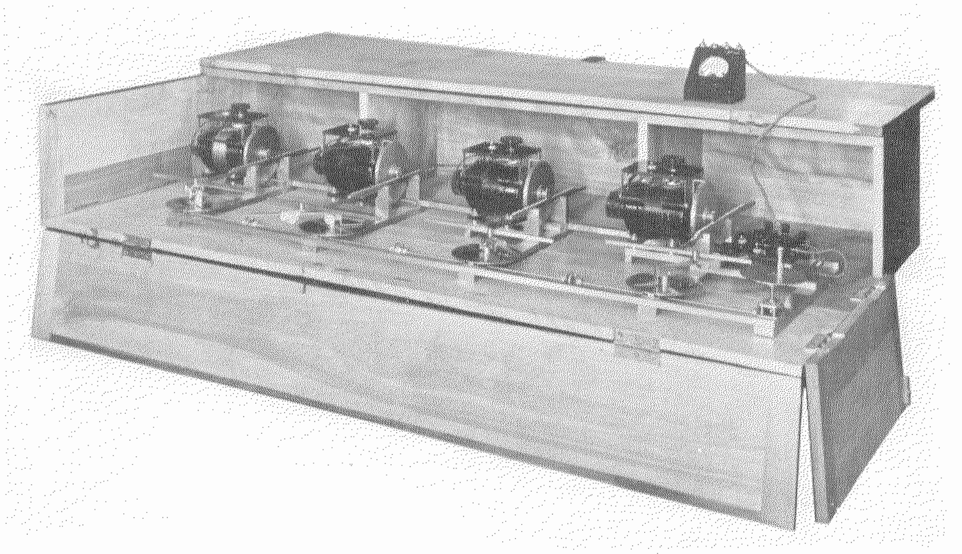

Fig. 1—Machine for Calculating the Polar Diagram

calculations with the aid of a machine. An examination of the problem resulted in the design of the machine herein described. The design details were completed in August 1940 but, owing to war circumstances, the actual construction was not finished until March 1941.

It will be noticed that the technique employed results in a mechanical-electrical system which appears to be simpler to make and to operate than any system which is either purely mechanical or purely electrical.

2. *Polar Diagrams of Antenna Systems*

At any distant point the field due to a number of antennae is the vector sum of the component fields which are derived from the separate antenna currents. In practice it is, moreover, always reasonable to assume that the point under consideration is far removed from the antennae compared with the spacing between them, i.e., that the attenuation due to distance is the same for each antenna.

The relative phases of the component fields depend on two factors, the initial starting phase (i.e., the relative phase of the antenna current) and the path differences from the antennae to the point. The relative magnitudes of the component fields depend only on the relative current strengths in the antennae which produce them.

These features may be illustrated by a simple example of a directional antenna system such as shown in Fig. 2. With such an antenna system one should set up a vector diagram for the resultant field at P as shown in Fig. 3.

The symbols used throughout this article have the following meanings:

E_n = field due to antenna n, directly proportional to amplitude of current I_n;

β_n = relative phase of current I_n;

d_n = distance of antenna from reference point expressed in degrees (one wavelength equals 360°);

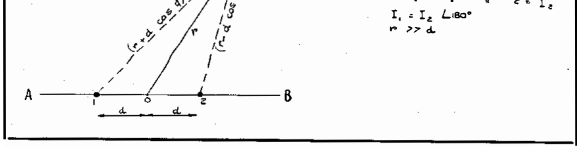

Fig. 2.

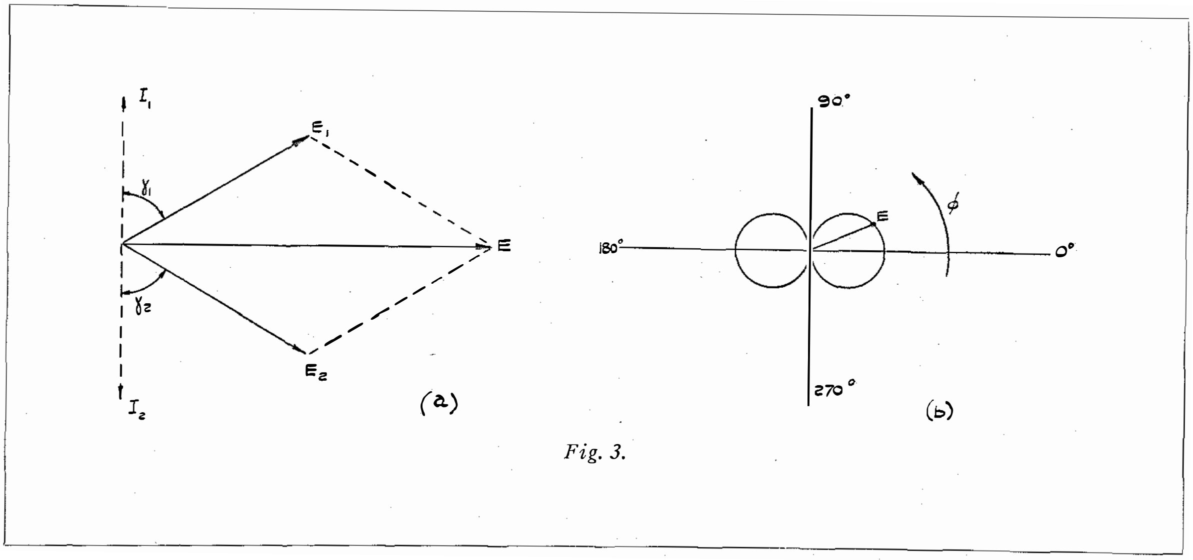

Fig. 3.

α_n = angular position of antenna with respect to reference line;

ϕ = angular position of distant point.

It will be seen that, compared with a radiation starting at the reference point 0, the phase of the signal from No. 1 is retarded by ($d \cos \phi$) degrees whilst that from No. 2 is advanced by ($d \cos \phi$) degrees. In calculating these phase differences d must be expressed in degrees where each wavelength of distance equals 360°.

In addition there was an initial phase difference of 180° between I_1 and I_2. Consequently the relative phases of signals E_1 and E_2 are as shown in Fig. 3.

Obviously the resultant is zero when $\phi = 90°$ and 270° and a maximum when $\phi = 0°$ and 180° (provided $d < \lambda/4$). In fact the resultant polar pattern is the familiar figure 8 shape as used in D.F. work.

In the example just given the selected reference point 0 is midway between the two antennae and the value of ϕ is 0° when P is in line with AB. However, any arbitrary reference point and reference line ($\phi = 0°$) could have been chosen. In such cases the general expression for γ, the phase due to path difference, becomes:

$$\gamma = [d_n \cos (\phi + \alpha_n)] \text{ degrees.}$$

In the above expression the position of the antenna has been specified in polar fashion and has coordinates d_n, α_n (see Fig. 4).

The field at a distant point in the general case is then given by:

E = Vector sum of E_n

$$< [d_n \cos (\phi + \alpha_n) + \beta_n] \text{ degrees.} \quad (1)$$

The mathematical problem is now that of computing the value of the right hand side of equation (1). This normally involves setting up a table for cos ($\phi + \alpha_n$) degrees with values of ϕ from 0° to 360° in steps of say 10°. These values are then multiplied by d_n degrees and to each of the resultants β_n degrees is added. This must be done for each separate antenna. The resultant vectors are then resolved into their sine and cosine components, each multiplied by the appropriate E_n. These components are then added and finally the resultant is obtained as the square root of the sum of the squares.

Going through this process for every 10° or so is obviously a tedious and time absorbing procedure. On the machine it is possible to produce

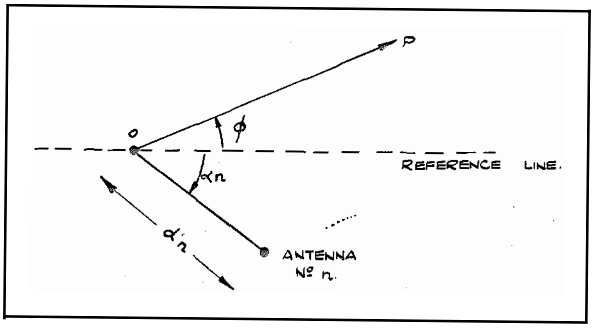

Fig. 4.

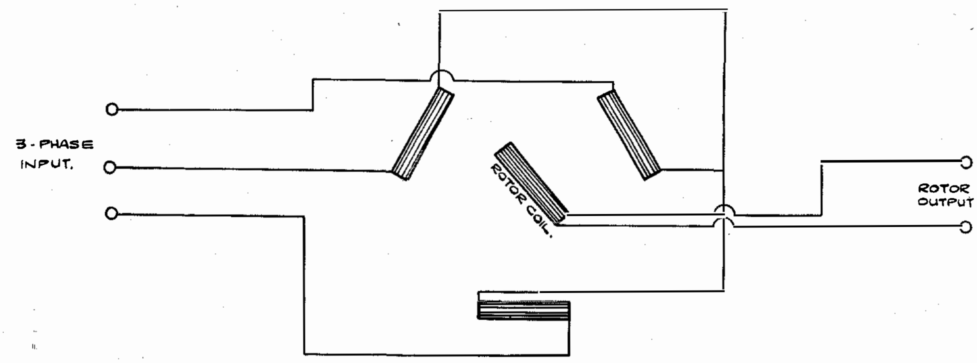

Fig. 5.

data for a curve in 15 minutes whereas normal calculation procedure would take a whole day.

3. *Principle of Operation*

The machine uses "Selsyn" motors which have a three phase stator and a single phase rotor. In this particular case, however, they are used as transformers rather than motors and use is made of the special property that the winding is such that the phase of the E.M.F. in the rotor is *exactly proportional to the angular position of the rotor.*

If, therefore, a number of such motors are connected with their three phase primaries in parallel, the phases of the secondary (i.e., rotor) voltages will be determined by the angular position of the individual rotors (Fig. 5).

The rotors are not allowed to revolve in the normal fashion but are restrained in certain angular positions which represent the phases of the received voltage components. By putting a potentiometer across each secondary, the magnitude of each voltage vector can be adjusted to correspond to a given antenna current. Furthermore, by connecting the secondaries in series and by measuring the total voltage with a high impedance voltmeter, the vector sum of all the secondary voltages is obtained.

The phase of the voltage, which depends on the position of the rotor, corresponds to the angle $[d_n \cos(\phi+\alpha_n)+\beta_n]$ degrees in equation (1). This angle is obtained mechanically in the following manner:

The arm A carries a pin P against which is pressed (by the torque of the motor) a T-shaped arm T (Fig. 6). This arm is constrained by guides G to move up and down only along the line of the rack which forms the centre piece of the arm T. As the arm A rotates the rack moves sinusoidally. The amplitude of the movement of the rack depends on the radial distance "r" of the pin P from the centre O. This distance is calibrated directly in terms of d_n expressed in wavelengths, the calibration being such that:

$$\text{Unit } d_n/\lambda = \text{“}l\text{” inches (See Fig. 6).}$$

Thus the rotor follows the law $(d_n \cos\phi)$ degrees where ϕ is the angular position of the arm A. It will be noticed that the thickness of the pin introduces no error since it is taken up by the initial setting of the disc D.

The angular position of the antenna is quite simply introduced by different settings of the starting angle of A, i.e., A is initially set to an angle α_n degrees. The rotor, therefore, follows the law $[d_n \cos(\phi+\alpha_n)]$ degrees. Further, by giving the initial setting of the graduated disc D the value β_n, there is obtained from the rotor an A.C. voltage whose phase is a complete representation of the term:

$$[d_n \cos(\phi+\alpha_n)+\beta_n] \text{ degrees.}$$

The magnitude of this A.C. voltage is adjusted to be proportional to the antenna current. Each antenna is represented by such a motor and its corresponding linkage. Finally the whole set of linkages is driven off the same main shaft. Consequently the voltage measured across the secondaries combined in series gives the resultant amplitude for any particular setting of ϕ.

By choosing an antenna as the reference point 0 (see Fig. 4) and by considering the phase of that particular antenna as representing zero phase, one can include an antenna which will require no motor to alter its relative phase as ϕ is varied.

This was done in the herein described apparatus which consequently gives five antenna calculations with only four motors. A circuit diagram of the apparatus is shown in Fig. 7.

4. *Method of Operation*

Given the antenna system represented by Fig. 8-*A*, the problem is to determine the polar diagram, Fig. 8-*B*. First of all, it is convenient to choose the centremost antenna 0 as the reference point. Further, the reference line may be taken to be the line joining 0 to 1, in which case $\alpha_1 = 0°$. This means that the arm *A* associated with antenna 1 is initially set at 0°; hence, ϕ is read directly.

4.1 Setting for Antenna 0

With S_0 (Fig. 7) switched on but all the others off, E_0 is set so that the voltmeter reads, say,

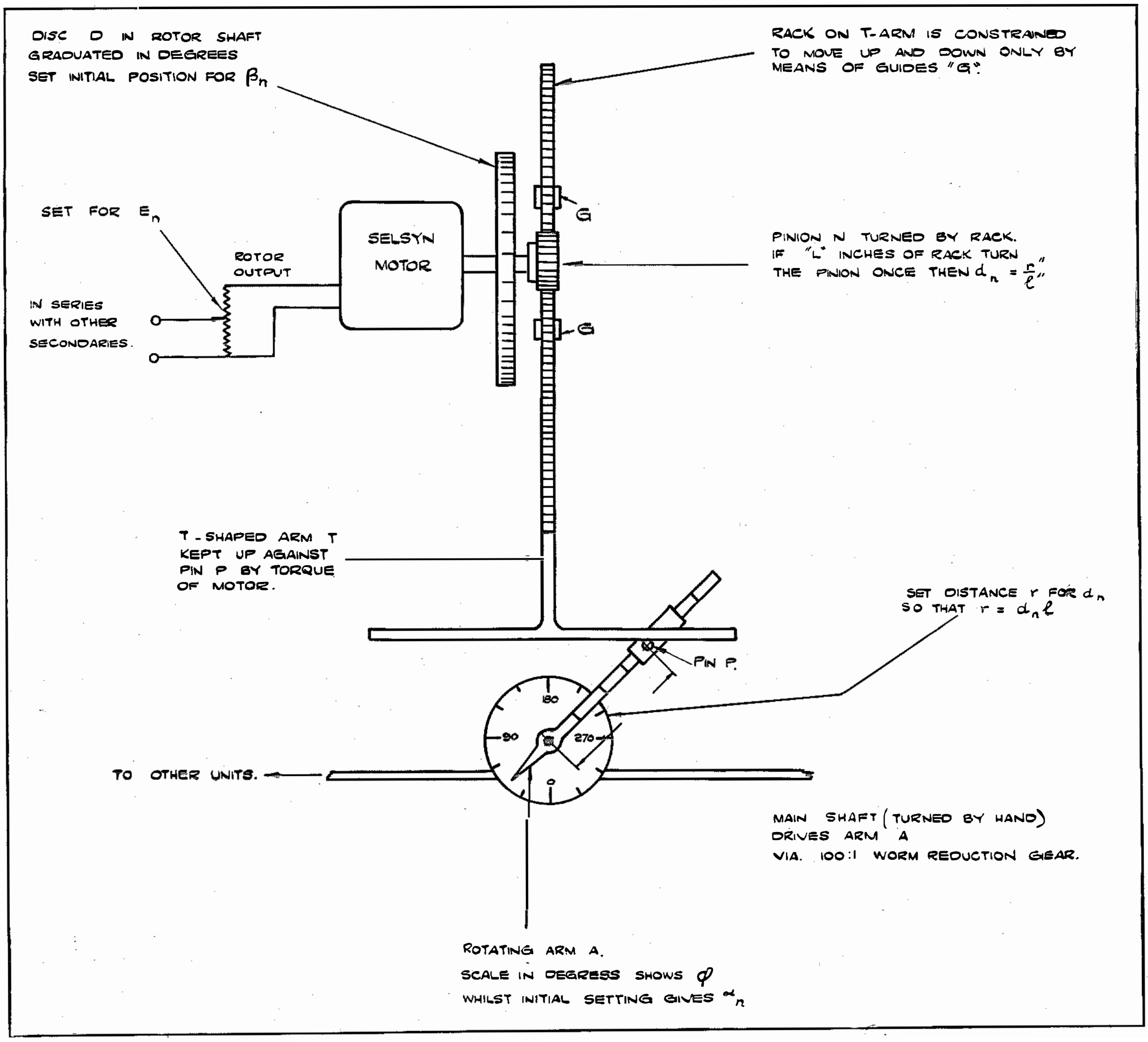

Fig. 6.

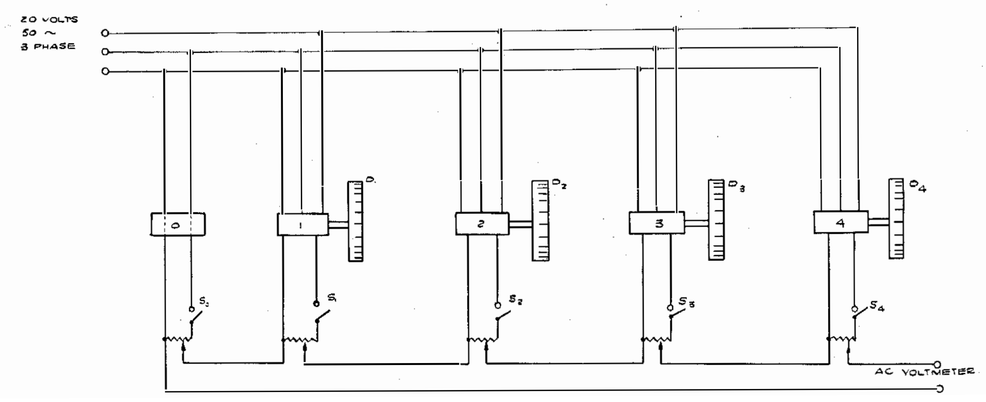

Fig. 7.

10V. This value therefore represents unit antenna current.

4.2 Setting for Antenna 1

S_0 is then switched off and S_1 is switched on. Next E_1, which in this case is adjusted to give a reading of 25V. on the voltmeter, represents an antenna current 2.5 times that in antenna 0.

To make the adjustment for β_1, the pin P_1 is moved to the centre of the arm A. Then the pinion N_1 (Fig. 6) is loosened and D_1 is turned until it reads 90°. The arm T_1 is pushed up against P_1 and the pinion is then tightened again. In this way the β_1 adjustment is made with $r_1=0$ and, therefore, the relative phase of the antenna current is registered under the required condition—that there is as yet no phase difference due to distance.

Then the pin P_1 is moved along the arm A_1 until the reading shows 0.5, which is the value of d_1 in terms of wavelengths.

Finally, since $\alpha_1=0°$, the pointer of A_1 is set to read 0°, whereupon D rotates to take up the distance term $(d_1 \cos \alpha_1)$ degrees which is now introduced.

4.3 Setting for other Antennae

Motors 2 and 3 are set up with exactly the same procedure as for Motor 1. The switches S_0 to S_3 are then all put on together and the curve can be taken.

The whole setting up process is quicker than one might imagine from the description and can easily be done in five minutes. By turning the main shaft, all the motors are operated simultaneously. Each one follows the correct law for its respective antenna. Then from the dial of A_1 (i.e., where $\alpha_n=0°$) ϕ is read directly and the corresponding voltmeter reading noted.

5. Examples of Results Obtained

5.1 *Amplitude Accuracy*

The accuracy of the machine was first tested on the three antenna system shown in Fig. 9. The polar diagram is shown both calculated and as obtained on the machine. By comparing them it can be seen that the errors vary from 0 to 5%.

The accuracy of the Selsyn motors by themselves was previously found to be within 2%. Thus the differences are due to inaccuracies in the mechanical linkage.

The degree of accuracy could be doubled if d_n were limited to $\leqq 1\lambda$ instead of 2λ (i.e., by using pinions of twice the diameter) but this refinement is not justified since in practical field measurements quite substantial variations from the theoretical patterns will occur. In fact a measured field pattern lying everywhere within 5% of the calculated values would be something of a phenomenon.

5.2 *Angular Accuracy*

An example of the accuracy with reference to ϕ is given in Fig. 9. In this example the angles for zero radiation were given by the machine as occurring at 27° and 33° from either side of the approach path. Exact calculation gave the values for these zeros as 27.2° and 32.8°.

5.3 *Application to a 5 Antenna System*

Among the many types of antenna systems, which have been tried for Instrument Approach

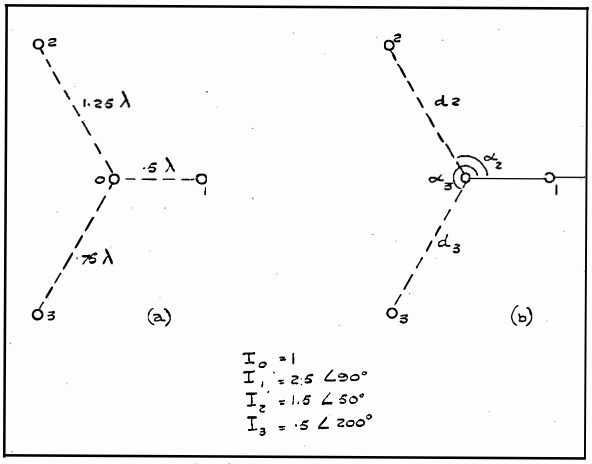

Fig. 8A.

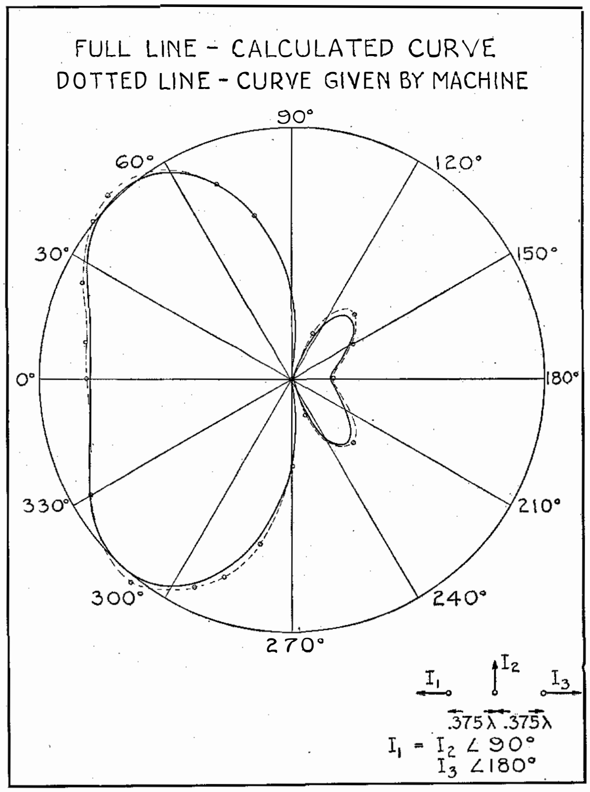

Fig. 8B.

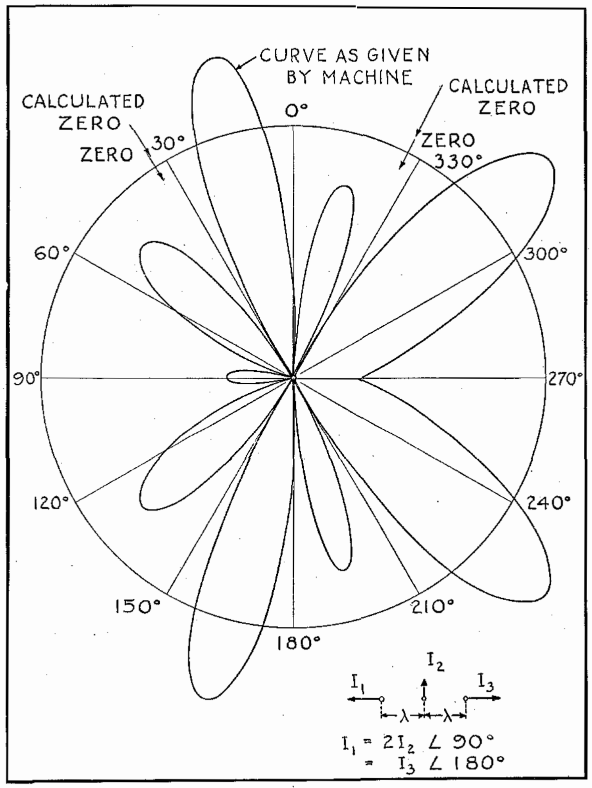

Fig. 9.

Systems, is one in which the antennae are spaced in the manner shown in Fig. 10 (see, for example, Hodgson, J. I. E. E. Sept. 1940). The reasons governing the choice of spacings, current phasings, etc., are not considered in the present article, but families of curves are given showing the effect of varying some of the parameters of such a system. It will be appreciated that the machine does not need complete resetting between such curves since only one variable at a time is altered.

From these curves (Fig. 10) one can select the most suitable polar diagram for Instrument Approach Systems. Inspection shows that curve VI(*b*) is the best. The value of .6λ for d_1 and d_2 was tried because it was thought that a sharper approach beam might result, but curves I to III show that the side discrimination is inadequate in such cases.

The final step requires taking a family of curves whose parameters are small variations about the values chosen in VI(*b*). In this way the practical tolerances can be determined with little trouble.

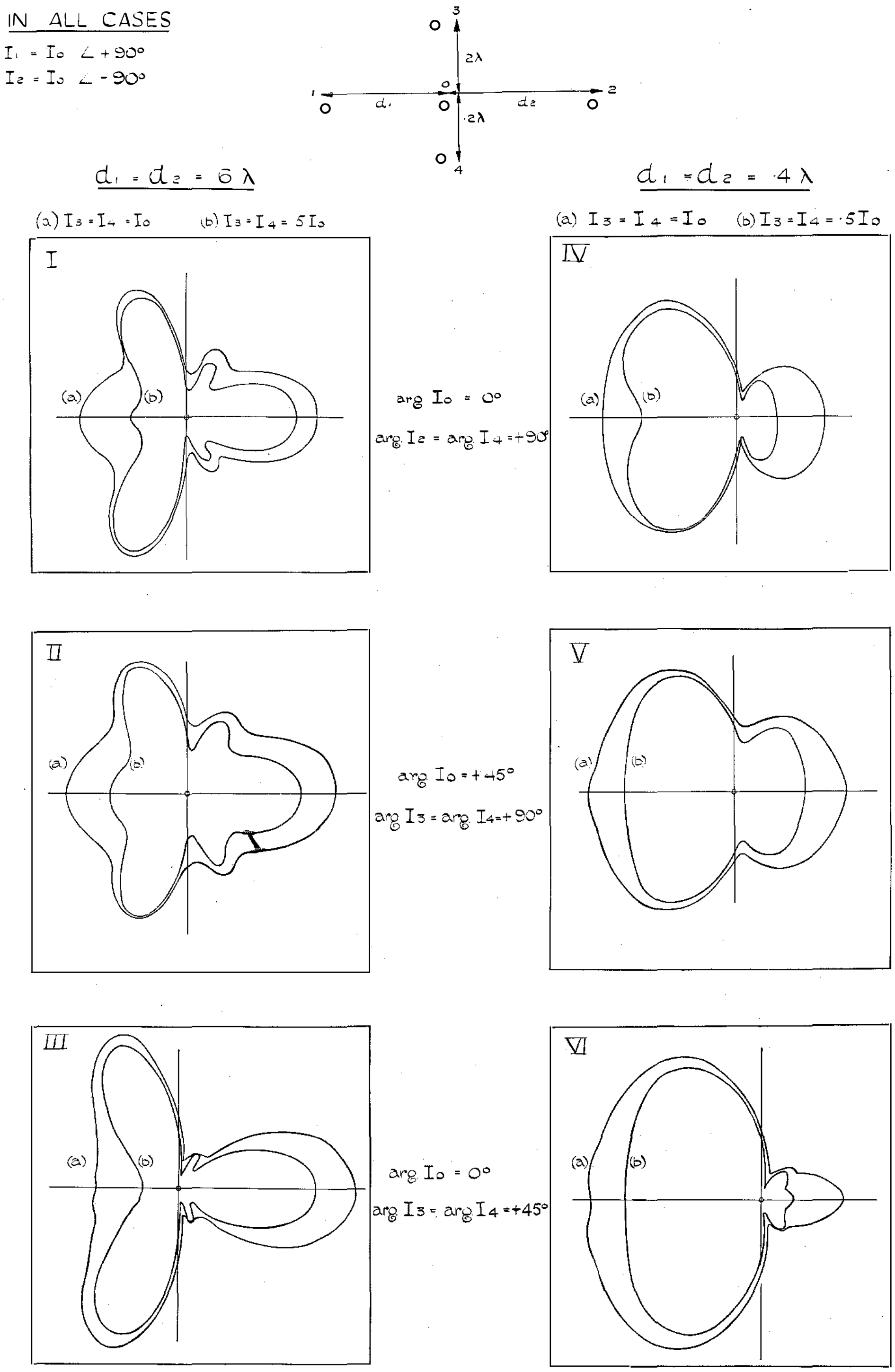
IN ALL CASES
I₁ = I₀ ∠ +90°
I₂ = I₀ ∠ -90°
d₁ = d₂ = 6 λ
d₁ = d₂ = 4 λ
(a) I₃ = I₄ = I₀ (b) I₃ = I₄ = 5 I₀
(a) I₃ = I₄ = I₀ (b) I₃ = I₄ = ·5 I₀
arg I₀ = 0°
arg I₂ = arg I₄ = +90°
arg I₀ = +45°
arg I₃ = arg I₄ = +90°
arg I₀ = 0°
arg I₃ = arg I₄ = +45°
I
II
III
IV
V
VI
(a)
(b)

Fig. 10.

The calculation of these twelve curves would in the ordinary way take approximately a week, whereas on the machine they were all done in one morning.

5.4 *Study of the "Inverse" Problem*

The machine has also proved itself of great utility in the "inverse" problem, i.e., in determining the current and phase relationships which must exist in an antenna system when a certain polar pattern is measured in the field.

In one particular case the field patterns were not as expected from theory, the departure from theory being outside the bounds of measuring errors. It was therefore obvious that the antennae were not being fed in the desired way (this may readily happen when the mutual antenna impedances are not all known). In order to discover the actual phase relationships and magnitudes of the currents existing in the antennae, a whole series of polar diagrams were made on the machine. By taking the one which corresponded most closely to the field pattern, the true phases and currents existing in the antennae were determined.

New 50-Kilowatt CBS International Broadcasters

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Editor's Note:

This article supplements an I.R.E. paper, "CBS International Broadcast Facilities," by A. B. Chamberlain, in the Proceedings of the I.R.E., March, 1942. For detailed information on the antenna system provided for the new stations of the Columbia Broadcasting System, Inc., the reader is referred to the I.R.E. publication.

INTERNATIONAL broadcasting is recognized as a prime factor in the conduct of the present global war since it provides means for rapid interchange of ideas with friendly nations and presents a unique medium for contacting peoples of enemy nations. Among the foremost shortwave radio broadcast stations in the U.S.A. are the CBS International Broadcasters located on Long Island, New York, which transmit around the clock in 23 languages and dialects to South America, Central America, the West Indies, Mexico, Europe, Africa and Asia.

Inaugurated as a part of the Columbia Broadcasting System January 1, 1942, the new station now operates regularly with three transmitters on the air simultaneously: two 50-kilowatt carriers provided by new equipment designed and manufactured by the Federal Telephone and Radio Corporation to meet CBS specifications, and the 10-kilowatt carrier of an older unit which was moved to Long Island from Wayne, New Jersey.

The transmitters operate with a total of 13 directive arrays, using nine frequencies from 6 to 22 megacycles. The antenna design provides a gain as high as 16 db over a conventional half-

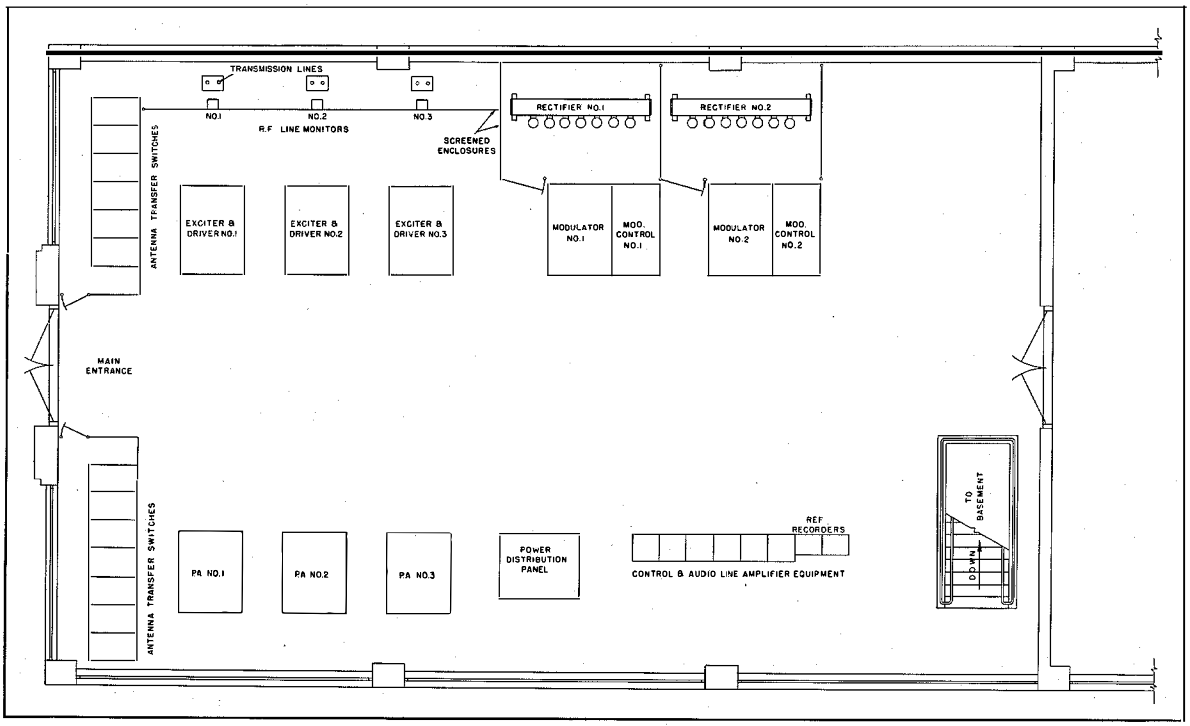


Fig. 1—Station Layout, Main Floor. (Ten kilowatt transmitter not shown in Figs. 1 and 2.)

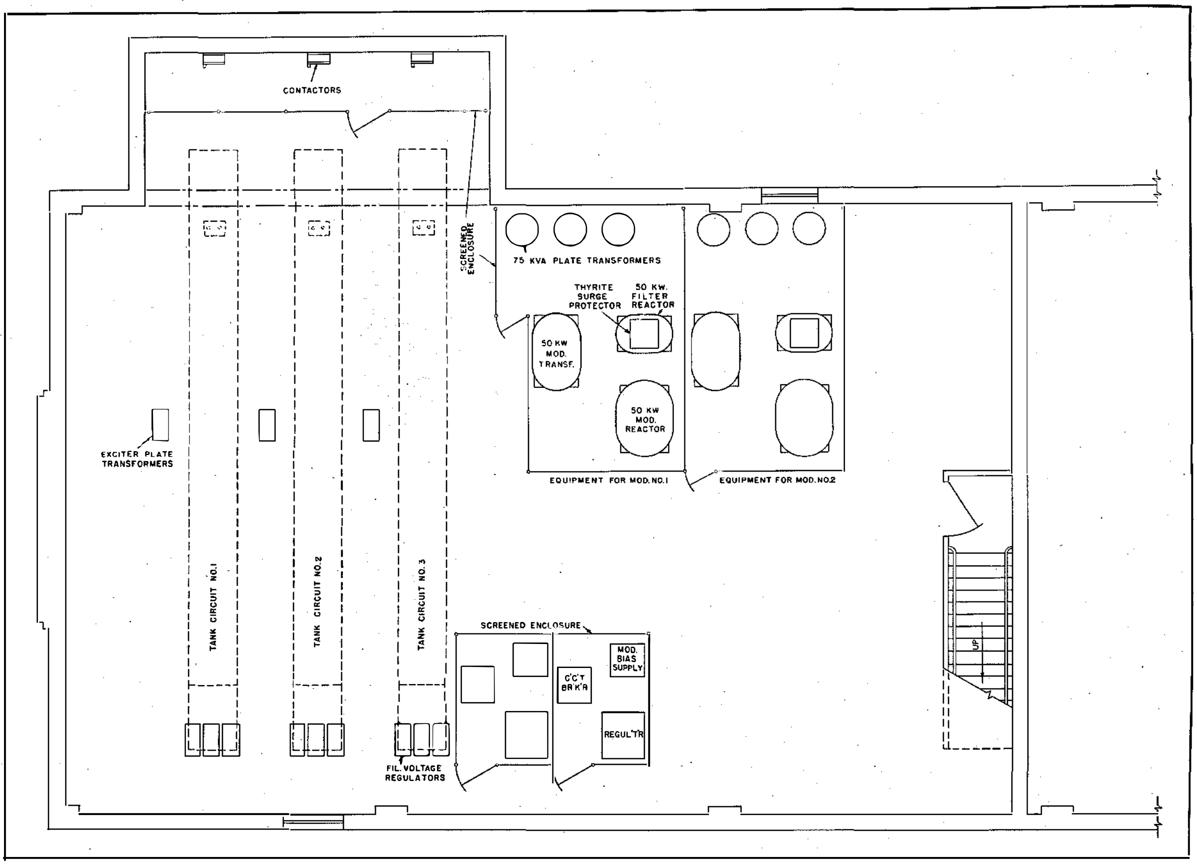


Fig. 2—Station Layout, Basement.

wave antenna in free space, due to the directional characteristics, making the effective radiation equivalent to almost 2000 kilowatts.

The Columbia Broadcasting System station is located on the 1200-acre site of the Mackay Radio and Telegraph Company's overseas shortwave commercial radio stations on Long Island. In one case, the CBS transmitters are operated on a Mackay antenna simultaneously with Mackay transmissions. This is practicable since the type of antenna employed functions efficiently with more than one transmitter, provided the frequencies are separated at least five per cent. Antennas, transmission lines, and special antenna switching gear were designed and built by Mackay Radio.

All the CBS transmitters are housed in a new, single-story wing, 40 x 60 feet, with basement, added to the existing Mackay transmitter building. Layout of the equipment on the two levels is shown in Figs. 1 and 2. From these illustrations it will be noted that three exciters and three 50-kilowatt final amplifiers are provided. The additional RF equipment allows the operators to preset the frequency of one RF section while the other two RF sections are being operated simultaneously. Instantaneous changeover to the preset frequency may then be accomplished by operating the specially designed antenna switch.

Design features of this shortwave station are similar in many ways to the new 50-kilowatt CBS medium-wave broadcast transmitter WABC,[1] the shortwave transmitters differing principally in the fact that they must be capable of rapid changeover while the medium-wave transmitter normally operates continuously on a single frequency. This means not only that all RF circuits must be designed for higher frequencies, with accompanying greater problems of insulation and reduction of radiation losses, but they must also

[1] "WABC-Key Station of the Columbia Broadcasting System," by E. M. Ostlund, *El. Com.*, Vol. 21, No. 1, 1942.

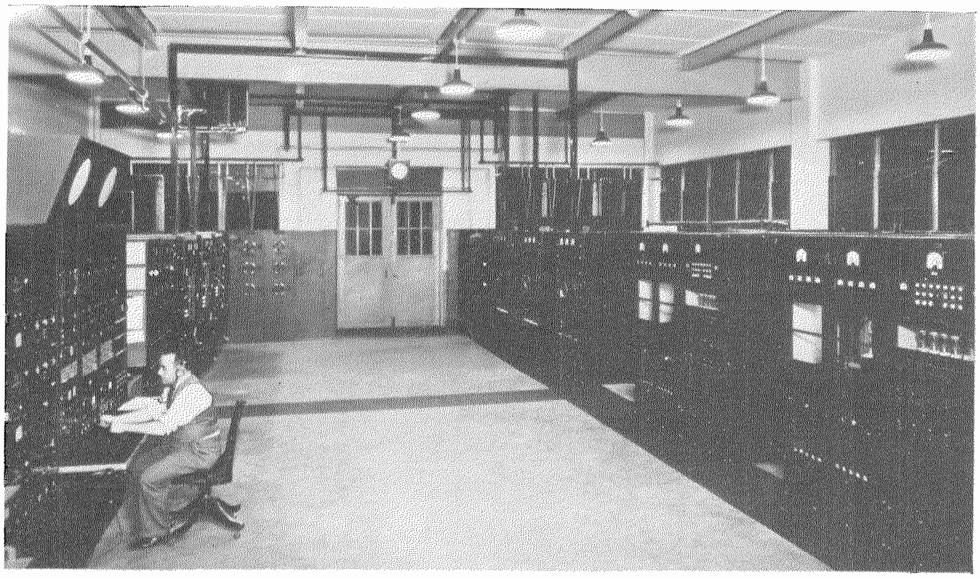


Fig. 3—General View of Station.

be made quickly adjustable. In the shortwave transmitters, the frequency adjustment range is 16 million cycles, sixteen times the entire medium-wave broadcast channel.

Although the design and construction of the RF portions of these transmitters are quite different from those of the WABC 50-kilowatt transmitter, the audio frequency, modulation, and power supply units are similar. Since the transmitters for both stations were built by the Federal Corporation, many of the same features of design that have proved so reliable and efficient at WABC were incorporated in the shortwave transmitters. The 12-kilovolt rectifier units in the two cases are identical. Except for a different arrangement of components, the audio amplifier-modulator units also are identical.

Inasmuch as operating practice on broadcasting stations does not permit long station breaks, the shortwave transmitters were constructed for fast and simple frequency shifts. In providing a coordinated design to accomplish this result in a foolproof manner, two unique design features of special interest were evolved; both are described hereinafter. One is the plate line and harmonic suppressor on which frequency changes are accomplished by motor-driven shorting bars arranged to stop at any of six preset points in much the same manner as a push-button, motor-driven automatic tuner on a radio receiver operates. (The motor tuner requires $1\frac{1}{2}$-horsepower motors and the tuning lines extend underneath almost the entire width of the station floor.) The other feature is antenna switching gear which permits instantaneous changeover of any of the three RF power amplifiers to any of the 13 antenna arrays used with the 50-kilowatt transmitters. These and other wave-changing controls are so well coordinated that it is possible to shift frequency on any of the three 50-kilowatt RF units in five minutes.

Station Layout

A general view of the wing housing the CBS equipment is shown in Fig. 3. By referring to the station plan, Fig. 1, the units visible in the illustration may be identified. In the left foreground may be seen the racks holding the line amplifiers, gain controls, and monitoring equipment necessary for simultaneous operation of three transmitters. Included are frequency monitors, RF modulator monitors, a tone generator, and a noise level and distortion meter. Control of the application of power to all RF equipment and to the modulators and main rectifiers is obtained from a single panel on the rack assembly.

Beyond the rack assembly may be seen the power distribution switchboard, followed by the three 50-kilowatt power amplifiers. The two halves of the antenna distribution switchboard are arranged across the far end of the wing with the interconnecting transmission lines carried up over the doorway. In the right foreground are the two modulator units, and beyond these are the three RF exciter units.

The two 12,000-volt rectifiers are located on racks mounted within fenced enclosures immediately to the rear of each modulator unit. The filter capacitor units are also mounted within these enclosures. Chokes and transformers are located in the basement directly below each unit. These power supplies provide plate power to the water-cooled final amplifier and modulator tubes.

All large transformers, reactors, circuit breakers, and voltage regulators are located in the basement. Separate enclosures surround each group of high tension equipment associated with a power supply or modulator, and special locks and interlocks are provided for the enclosure doors so that an enclosed area can be entered only when the equipment is not energized. Operating personnel are, therefore, completely protected from accidental contact with high voltage circuits.

Radio Frequency Units

Fig. 4 is a simplified schematic diagram of the RF circuits. For the most part these circuits follow conventional design practice. All but the 50-kilowatt stages are contained within single units referred to as the RF drivers; the three final amplifiers are housed in separate units.

Two-conductor, balanced transmission lines connect the outputs of the RF drivers to the grid circuits of the power amplifiers. These lines are completely shielded by copper pipes of rectangular cross-section. The three lines, in their shields, are shown in Fig. 3 running to the ceiling

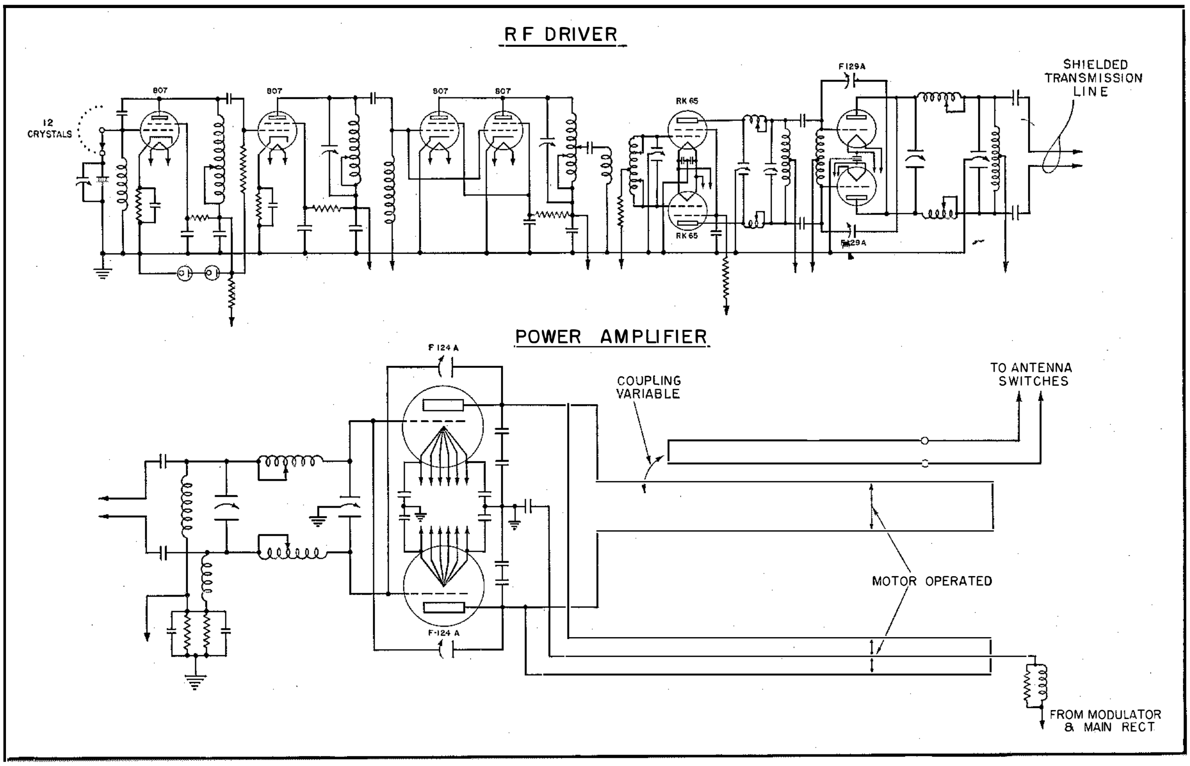


Fig. 4—Circuit of RF Driver and Power Amplifier.

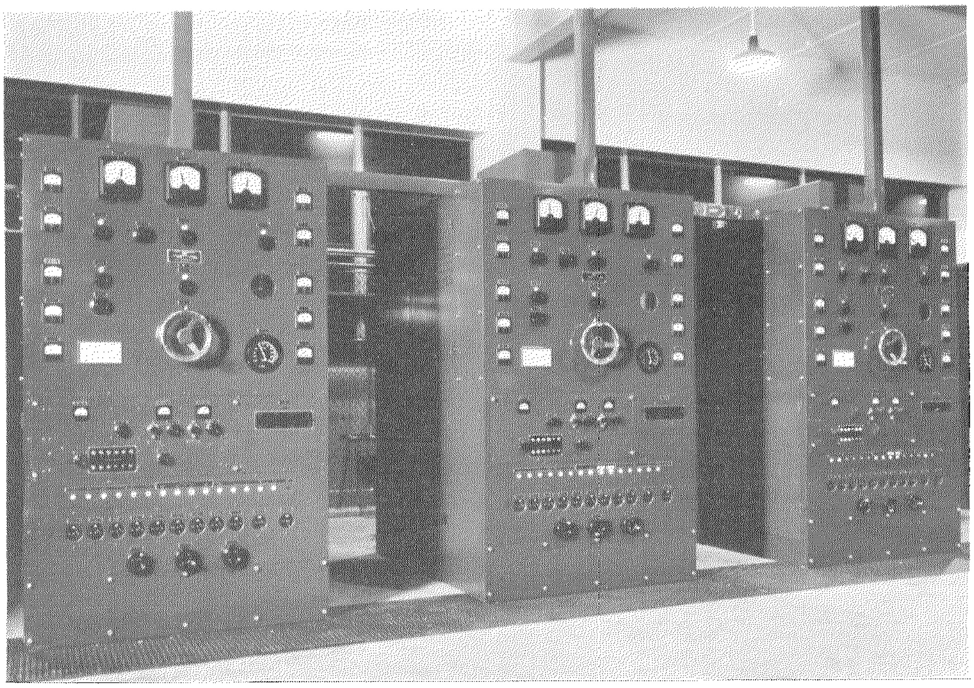


Fig. 5—View of RF Drivers.

from the tops of the RF drivers on the right across to the final amplifiers. Interconnecting transmission lines are provided between the driver units so that any RF driver may be used to excite any power amplifier. Each driver unit is capable of delivering 5000 watts to the power amplifier grids.

RF Drivers

A view of the three RF drivers is shown in Fig. 5. The crystal-controlled oscillator and the frequency doubler stages are contained in one unit which, like a filing cabinet drawer, may be pulled out from the front of the RF driver for servicing. Controls are provided on the front panel to permit frequency changes of all circuits except the driver output stage plate circuit, the inductance of which may be changed readily by manipulation of coil-shorting bars accessible from a side door.

Plate and bias supply rectifiers, automatic filament voltage regulators, and all filament transformers associated with the RF driver are contained within the unit with the exception of the transformer for the three-phase, full-wave rectifier supplying 5000 volts to the output stage and 2500 volts to the buffer stage. The entire unit is ventilated by a blower which draws air in through a filter on the side and circulates it around all parts requiring forced draft ventilation.

Power Amplifier

Two Federal F-124-A, water-cooled triodes are employed in each power amplifier in a balanced circuit using a pi-network input and a plate circuit designed to take advantage of the high efficiency and flexibility of parallel linear conductors. A view of the power amplifiers is shown in Fig. 6.

The principal characteristics of the F-124-A tube are as follows:

Filament: Six terminals—13.6 volts per terminal to a common internal connection—68.5 amperes per strand.

Amplification Factor:	42
Mutual Conductance:	14,000 micromhos
Anode Dissipation:	40 kilowatts
Direct Inter-Electrode Capacitances:	
Plate-to-grid	29 $\mu\mu$f.
Grid-to-filament	37 $\mu\mu$f.
Plate-to-filament	5 $\mu\mu$f.
Overall Dimensions:	
Length	$25\frac{15}{16}$ inches
Diameter	$12\frac{1}{2}$ inches

Neutralization of the power amplifier is accomplished by a combination of fixed vacuum capacitor units, shunted by variable capacitors for fine adjustment. Adjustment of each grid circuit coil is varied in steps by means of taps to selector switches which short out various portions of the coils.

As previously stated, a 50-kilowatt, high frequency broadcast transmitter must be designed to provide efficient operation on a wide band of frequencies. In the lower power stages of the Long Island transmitters, frequency changes are made either with taps or shorting bars on the inductances, finer tuning being accomplished with variable capacitors. The inductance for the plate circuit of the power amplifier consists of a three-inch diameter copper pipe for each anode, both pipes running parallel for a distance of approximately 35 feet with a center-to-center separation of 12 inches. The resonant frequency of the circuit formed by this inductance loop shunted by the tube capacitance is varied by the shorting bar moved along the horizontal portion of the loop. Thus, each transmitter is continuously adjustable in frequency over its entire range of 6 to 22 megacycles. Hence, with the proper crystals, the transmitters will operate on any predetermined frequency in this range.

The copper pipes of each plate line extend directly below the F-124-A vacuum tubes through a hole in the floor to the basement and there continue horizontally across the basement area. Ceramic stand-off insulators support the pipes at intervals along their entire length. One set of supports is shown in Fig. 7. A second line, made up of three parallel pipes, is mounted directly below the plate line to provide harmonic suppression. Inductance of the harmonic suppression line is also varied by means of a shorting bar. When this line is tuned to the fundamental fre-

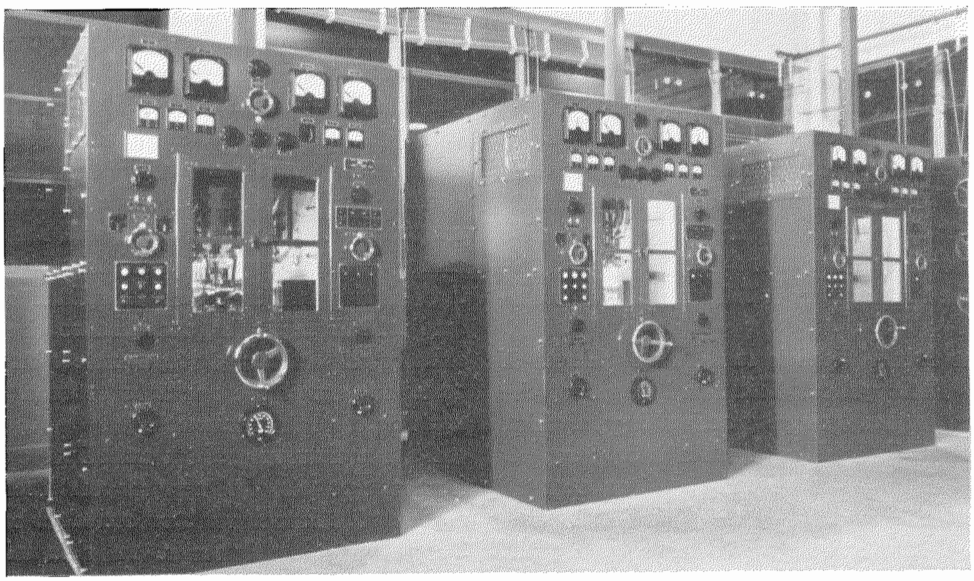


Fig. 6—View of Power Amplifiers.

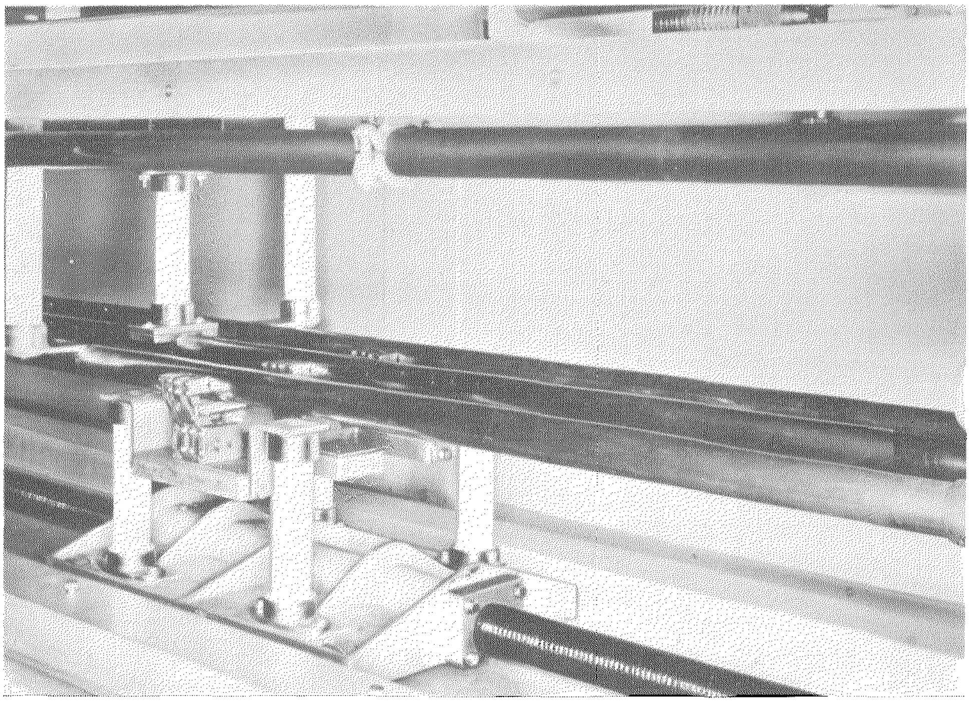


Fig. 7—View of Motor-Driven Harmonic Line Truck.

quency, a short circuit, in effect, for even order harmonics exists from each plate to ground, via the center conductor.

The plate and harmonic lines are contained in separately shielded compartments composed of aluminum frames and panels completely enclosing each set of lines. Each panel is equipped with an interlock switch so that if the panel is removed, the plate power will be turned off automatically.

Contact to the pipes is made through sets of "V"-type sliding shoes held firmly against the copper conductors by spring action fingers which are mounted, in each case, on a heavy copper plate. The copper plate is supported on ceramic stand-off insulators fastened to a dolly. This complete assembly is termed a carriage. It can be moved axially along the horizontal length of the conductors by means of a motor-driven lead screw or worm. A harmonic line carriage with its lead screw is shown in Fig. 7. A similar carriage for the plate line is operated from a screw directly below the plate conductors.

The three-phase, reversible, two-speed motors driving the lead screws are located at the ends of the lines away from the power amplifier anodes and are connected to the worms through V-belt couplings. The harmonic line and the plate line motors are interconnected electrically so that the two carriages travel over the lines simultaneously. Flexible shafts, attached to the opposite ends of the worms, drive counters on the front panel to permit the operator to read the exact location of each carriage.

Automatic tuning of the tank lines is controlled from the panels of the power amplifier units by means of channel selector switches and motor start-stop push buttons. A channel selector switch has six positions corresponding to six stops or positioning switches located along the carriage tracks. Each of the six positioning stops may be preset to any point along the line so that a channel may be set to any frequency within the range of the transmitter. When the channel selector switch is set to select one of the positioning stops, it also determines the direction in which the motors must turn to drive the carriages to the desired stop. Hence, when the motor start button is depressed, the carriages travel at high speed in the proper direction; power to the plates of the amplifier tubes is cut off automatically by an interlock relay during the traveling time and the motors stop when the carriages arrive at the proper point on the lines.

A non-locking vernier switch is also provided on the panel for each set of lines to permit non-automatic operation of each carriage back and forth at half-speed, with the plate power on, for fine adjustment. With this vernier adjustment, it is possible to tune the lines to additional frequencies besides the six preset frequencies, if necessary. Pilot lights on the panels light to show the motors are running.

Safety limit switches are located at each end of the lines to remove voltage from the motors and thus prevent overtravel if one of the position switches should fail to stop the carriages. Pilot lights associated with these switches, when lighted, inform the operator of the tripping of a safety switch. He can then return the carriage from the end of the line to a selected position by pressing the motor start button or by using the vernier switches.

The plate and harmonic line piping provides a convenient means of bringing cooling water to and from the tube anodes. The water connections of the pipes are such that water flows in series through the two tube jackets. Ceramic piping is employed for some distance before the water enters and after it leaves the transmitter in order to provide insulation for the modulated d-c voltage. The cooling water is provided by Mackay Radio from its centralized group of water pumps and force-draft, radiator type of heat exchangers.

Inductive coupling is employed between the plate line and the antenna switching system. Each inductive loop consists of two pipe conductors about thirty feet long mounted horizontally above and parallel to the plate line. The end nearest the tubes is shorted, with the midpoint of the shorting strap grounded, while the far end connects to the antenna transmission line through the special antenna switching assembly.

Coupling is varied by moving the two pipes forming the coupling loop horizontally so that at maximum coupling each pipe is directly over the two sections of the plate line. At minimum coupling, the two pipes are only two or three inches apart. In other words, variation in coupling is accomplished by changing the position of the coupling loop conductors in relation to the plate line conductors and by varying the area within the coupling loop. The coupling loop is varied by means of a handwheel on the front panel of the power amplifier unit.

Antenna Switching Mechanism

Design of a switching mechanism that would permit the outputs of the three 50-kilowatt power amplifiers to be connected to any three of the thirteen antennas efficiently was one of the major problems in the construction of the station. Since the potential at this point is 14,000 volts, RMS, or more, during modulation peaks, a high degree of insulation is required. Voltage breakdown tests were made to determine the comparative merits of various insulator designs under practical operating conditions,[2] and, as a result of the tests, special insulators and fittings were developed. Fig. 8 shows the interior of a portion of the antenna switching assembly, giving an idea of the large insulation spacing and oversize contacts necessary to assure high efficiency at frequencies up to 22 megacycles.

Since a switch is required for each power amplifier and one for each antenna, thirty-nine switch units make up the total assembly. Each switch is a four-pole, two-position device equipped with a handwheel for manual operation. A section of the switch panel is shown in Fig. 9. Each horizontal row connects to a particular amplifier while the vertical columns subdivide the antennas. As the nameplate at the top of each column clearly indicates the area covered by the antenna and its operating frequency, operation is extremely simple. Foolproof connection is assured by a system of mechanical and electrical interlocks which prevent switching the antennas with power on and also prevent connection of

[2] "Radio Frequency High Voltage Phenomena," by Andrew Alford and Sidney Pickles, *El. Com.*, Vol. 18, No. 2, 1939; *Elec. Engg.*, Vol. 59, March 1940.

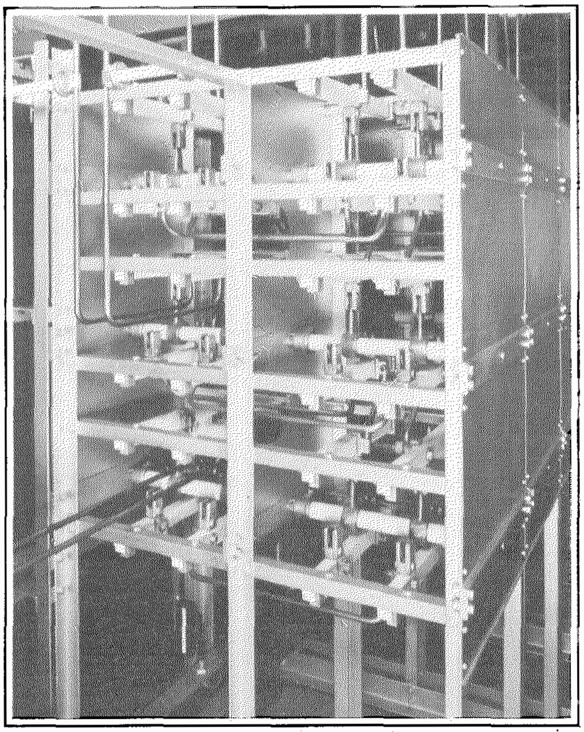


Fig. 8—View of Antenna Switches.

more than one amplifier at a time to an antenna. When an amplifier is properly switched to an antenna, a pilot light indicates that the antenna is in use.

Several of the antennas, directional to Europe, may have their directional beams rotated 180° so that they become directional to Mexico and Central America instead of to Europe. This is accomplished by means of remote-controlled switches at the antennas which reverse the connections to the transmission lines, interchanging the functions of the radiators and reflectors.

Modulators

Each of the two modulators employs two Federal F-125-A water-cooled triodes operating class AB_1. These tubes have similar physical dimensions to the Federal F-124-A tubes used in the final amplifiers, but the modulator tubes were designed specifically for audio frequency operation. The two tubes provide ample power to plate modulate the final amplifier.

The principal characteristics of the F-125-A tube are as follows:

Filament: Six terminals—13.6 volts per terminal to a common internal connection—65.5 amperes per strand.

Amplification Factor:	4.75
Mutual Conductance:	15,800 micromhos
Anode Dissipation:	40 kilowatts
Overall Dimensions:	
Length	$26\frac{3}{4}$ inches
Diameter	$12\frac{1}{2}$ inches

The modulator is driven by two Federal F-132-A triodes in push-pull, transformer-coupled to the grids of the modulator stage. These tubes also were designed by Federal especially for audio frequency operation. A view of the final audio amplifier and modulator tubes is shown in Fig. 10. Three stages of push-pull audio amplification precede this stage to provide amplification sufficient for taking audio signals directly from the line at a level of approximately 0 db.

Fig. 11 illustrates the audio amplifier and modulators. Audio frequency response from 40 to 10,000 cycles is plus or minus 0.5 db with reference to the 1000 cycle level. Harmonic distortion has been kept down to less than five

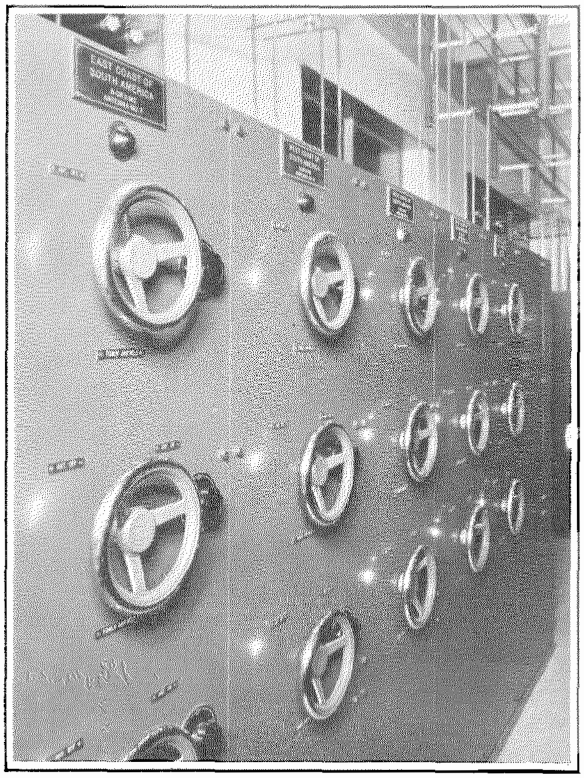


Fig. 9—View of Antenna Switching Panel.

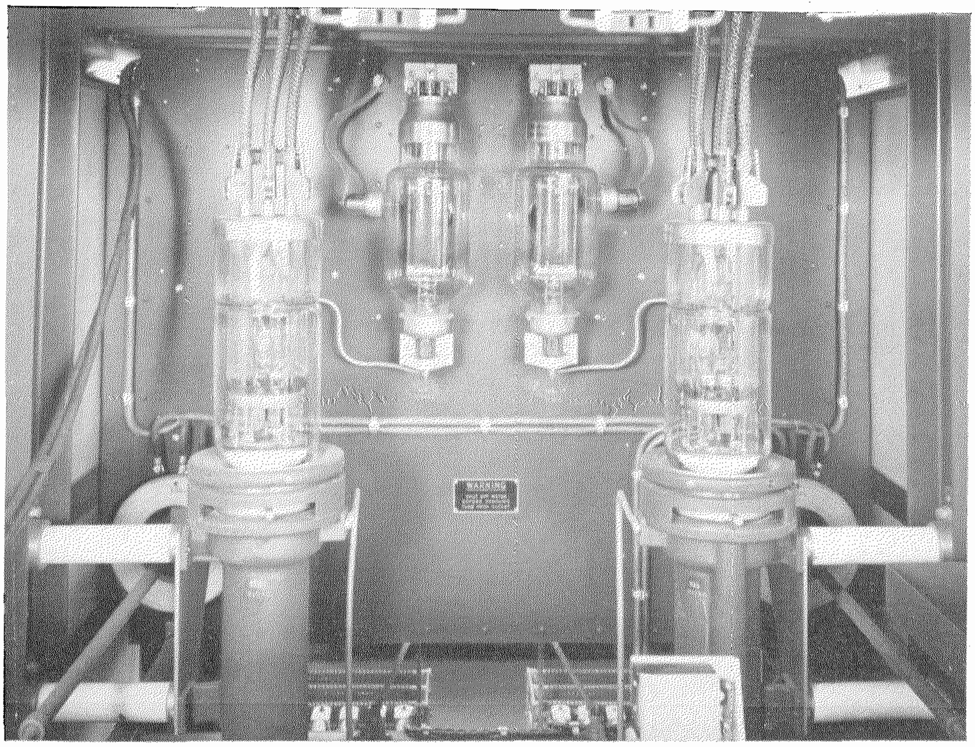


Fig. 10—Closeup View of Modulator and Final Audio Amplifier Tubes.

per cent from 50 to 7500 cycles at 100 per cent modulation. These performance characteristics are in accordance with the most modern practices in the broadcasting art.

Power Frequency Equipment

Power for the entire CBS station is obtained from 2300-volt, three-phase feeders brought from an outdoor transformer substation located about 1000 yards from the transmitter building. These feeders terminate in the portion of the building occupied by Mackay Radio, from which 2300-volt and 460-volt feeders are run to the CBS premises. After passing through a main breaker, the 2300-volt service is fed through fused cutouts to the oil circuit breakers of the two main rectifiers now installed. All 2300-volt primary equipment is located in the basement, including a group of instrument transformers for metering the 2300-volt circuits.

The 460-volt, three-phase feeders go directly into a power control unit located on the main floor near the power amplifiers shown at the left in Fig. 3. A 460-volt bus in this unit feeds a group of switches controlling the a-c power to the F-124-A and F-125-A tube filament supply circuits and the tuning motors of the power amplifier units. This bus also feeds an automatic voltage regulator supplying regulated 460 volts to a group of switches controlling a-c power to the F-129-A filaments and the 5000-volt rectifiers. The same bus also runs to a 460/230-volt transformer supplying regulated 230 volts to the low power circuits.

All switches on the power control units are of the circuit-breaker type with magnetic trip-out coils which open the switch on overload. This is also true of all switches located in the individual power circuits of the various units so that the use of fuses for overload protection has been avoided.

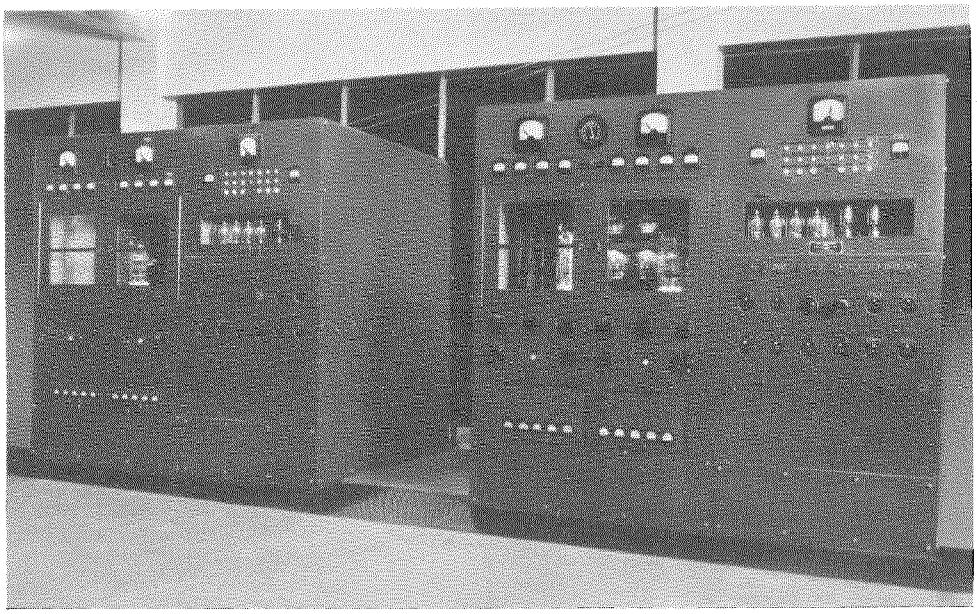


Fig. 11—View of Modulators.

A three-phase, full-wave rectifier circuit is employed in the main rectifier, requiring six Federal F-357-A hot cathode, mercury vapor rectifier tubes. A seventh tube (in a standby position) is included and is ready to be switched into service in case one of the active tubes fails. The voltage from this rectifier is controlled by a motor-operated induction voltage regulator in the primary circuit to the rectifier transformer bank. Control of the regulator may be either manual or automatic as desired, the rectifier output voltage thus obtained ranging from 8000 to 12,500 volts d.c. When the regulator is automatically operated, it will return to its lowest voltage position whenever the primary circuit breaker is opened so that, when the rectifier is switched on, it will start at its lowest voltage and slowly climb to any pre-determined value at which point the voltage will be maintained automatically. A single-phase, choke-input filter in the d-c output circuit has a relatively large capacitance to avoid undesirable coupling effects between the modulator and power amplifier.

The high voltage transformer bank is connected in delta-delta to permit operation at reduced power in the event that one of the transformers must be removed because of failure. Individual transformers are immersed in oil in separate steel tanks.

Control System

The control system has as its principal objective operation of an RF driver-power amplifier with any main rectifier-modulator. Fig. 12 illustrates the basic arrangement. Control facilities include provisions for a future third main rectifier-modulator which may also connect to any power amplifier.

Selection of any modulator and rectifier to be associated with any power amplifier is made at the power amplifier where push buttons operate the desired selector relays. These relays make a number of connections to the control circuits of the selected modulator, including door interlocks, power amplifier overload relays, the carrier cut-off circuit, and control of the main rectifier. After selection has been made, control of the power circuits to all RF and modulator units may be effected either at the units themselves or at the control panel over the operator's desk.

Electrical interlocking is employed to prevent accidental connection of two modulators to the same power amplifier.

The carrier cut-off device employed causes a momentary interruption to the carrier if the carrier current either rises or falls more than a few per cent from a pre-adjusted value. This is accomplished by balancing the voltage from a radio frequency rectifier against a voltage proportional to the main rectifier output, the differential operating a relay. Thus, if breakdown should occur in any radio frequency circuit, the excitation will be repeatedly interrupted until the trouble is cleared or the operator shuts down the equipment.

Conclusion

The CBS International Broadcasters are operating nearly 24 hours a day and 100 per cent of the station's time is now devoted directly to the war effort. On November 7, 1942, the United States Government leased, for the duration of the war, the facilities of this station as well as those of all other shortwave broadcasting stations throughout the nation. Two-thirds of the total air time of the CBS transmitters is utilized by the Office of War Information for information broadcasts to all parts of the world. For approximately eight hours a day, broadcasts are continued to South America to be rebroadcast over the CBS network there. This latter service is conducted in cooperation with the Office of Coordination of Inter-American Affairs.

With almost continuous operation for more than a year, the efficiency and reliability of the CBS broadcasters have been amply demonstrated. Under war conditions, breakdown would be costly in strategic materials and highly burdensome to train personnel; the long life as well as efficiency of the Federal tubes, specially designed for this type of service, thus are proving highly advantageous.

These broadcasters were built after more than three years of research and study. Their features —facilities for rapid and continuous frequency change, highly efficient directional antennas, a unique antenna distribution switching mechanism, a control system permitting maximum flexibility and efficiency in the connection and interconnection of the various units, as well as many factors of safety and efficiency—represent the culmination of this research by designers and builders with wide experience in the shortwave broadcast field. Of outstanding importance are the motor-tuned plate and harmonic lines and the special antenna switching equipment, particularly since they represent new contributions to the development of high-powered, shortwave broadcasting facilities. These two latter features, in fact, have proven particularly useful under present emergency conditions necessitating fast changes of frequencies and rapid connection to various directional beams. Further, the motor-tuned lines not only speed tuning, but they provide the unique feature of a 50-kilowatt, high frequency transmitter whose frequency is continuously variable with maximum output efficiency. Enthusiastic reports received daily on CBS broadcasts from network stations and foreign listeners give convincing testimony to the high technical capabilities of the station.

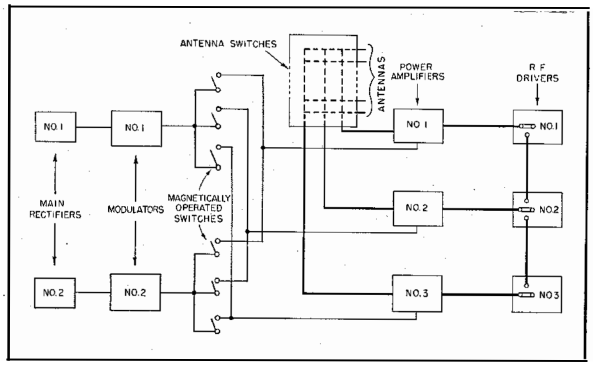
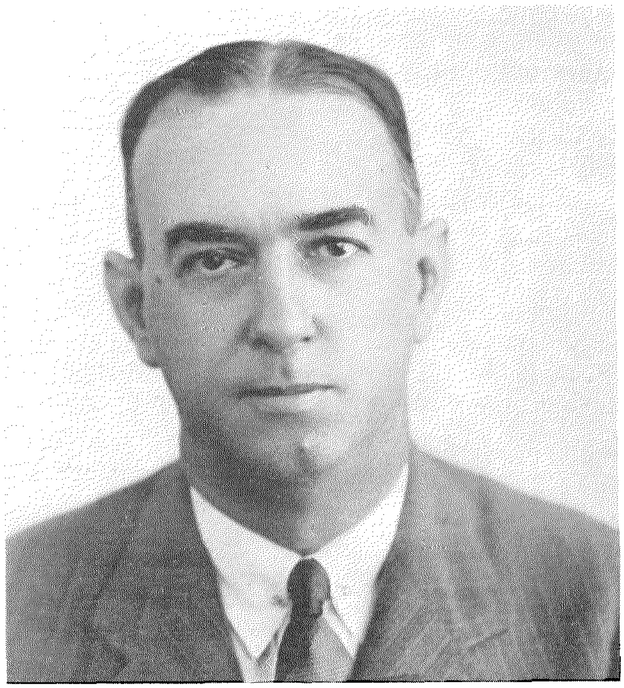


Fig. 12—Block Diagram of RF and Modulator Selector System.

All tests and experiments were conducted jointly by CBS, Federal, and Mackay Radio engineers, who together made available a wealth of information on powerful high frequency radio equipment. For their close cooperation in the solution of the many design and installation problems involved in this project, grateful acknowledgment is due Mr. E. K. Cohan, Director of Engineering and Mr. A. B. Chamberlain, Chief Engineer, as well as to Mr. F. J. Bleil and other engineers of the Columbia Broadcasting System.

In Memoriam



HENRY C. HART

Vice President in Charge of Operations and Member of the Board of Directors of the Cuban Telephone Company died suddenly in Havana on March 23, 1943. He also was a Director of the Cuban American Telephone and Telegraph Company and the Radio Corporation of Cuba, as well as of the Cuban American Chamber of Commerce, the American Club and the Country Club.

Born in Jacksonville, Florida, and graduated from the University of Tennessee, he came to Cuba in 1899. His contributions while in the Department of Public Works (Cuba) were outstanding. They included installation of street railway systems in Cienfuegos, Camaguey and Santiago de Cuba as well as railways in Central Cuba. In 1910, he joined the Cuban Telephone Company and directed the construction of the long distance telephone system and central offices throughout the island. In 1926, following the havoc wrought by the hurricane involving serious damage to the telephone plant, he reestablished the system in less than a month.

Mr. Hart's passing is an irreparable loss. He was preeminently a man of good will, a highly capable engineer, and prominent in social and civic affairs. Mr. Hart was a bachelor and is survived by his sister, Mrs. Frederick Morris of Havana.

Dehydration of Food by Radio Frequency Energy

By VERNON W. SHERMAN
Federal Telephone and Radio Corporation, Newark, New Jersey

THE Industrial Electronics Division of the Federal Telephone and Radio Corporation, in cooperation with the Office of the Quartermaster General of the United States Army, has developed a process of dehydrating food by means of radio frequency energy. The process makes possible, for the first time, removal of 99 per cent of the moisture content from a compressed vegetable block.

Conventional methods of dehydration rely on heat and forced air to remove water from vegetables. With these older processes, it is possible to remove 95 per cent of the moisture content without injury to the product. Vegetables so dehydrated can be reconstituted, *i.e.*, the normal water content can be restored by soaking in water, the vegetables returning to their original state and retaining their natural color and flavor.

Many root or semi-perishable vegetables, including beets, carrots, cabbage, onions and potatoes with a residual moisture content of five per cent, will keep only a few weeks in humid atmospheres and they cannot be packed satisfactorily inasmuch as the moisture present causes mold to form and makes them inedible. Consequently, attempts have been made to reduce the moisture content further. With conventional forced hot air drying many vegetables develop a tough, blackened skin known as "case hardening" when the moisture content is reduced below five per cent. "Case hardening" is a permanent change and prevents reconstitution to their former freshness and color.

The electronic dehydration method developed by Federal not only makes it possible to remove 99 per cent of the moisture but it also permits this high degree of dehydration after the vegetables have been compressed into a small block or briquette $6 \times 3 \times \frac{3}{4}$ inches. As will be recognized by those familiar with dehydration processes, compression of vegetables prior to total dehydration is an unprecedented procedure. Other processes require exposure of as much of the vegetable surface as possible to facilitate evaporation.

With all but one per cent of the moisture removed, it is possible to pack all types of dehydrated vegetables in sealed containers and transport them to any part of the world without danger of decomposition. Extensive studies have shown that the length of time vegetables may be kept in good condition increases very greatly as the moisture content approaches one per cent. Evidence now indicates that vegetables dehydrated by the electronic method will not deteriorate over a period of one to two years even in hot, humid climates.

Vegetables reconstituted after electronic dehydration may be cooked and served the same as fresh vegetables. Reconstitution is accomplished by soaking the vegetables in water. They then return to their original color and consistency and retain their normal taste and aroma. The vitamin content of electronically dehydrated vegetables is especially high due apparently to the much shorter processing time.

The exact method of dehydration cannot be disclosed at present. Briefly, however, 80 per cent of the moisture is removed by conventional methods, leaving the vegetables pliable but without formation of "case hardening." The vegetables are then compressed into bricks and the remaining moisture is removed electronically after which they are ready to be wrapped in paper, wax coated, packed and shipped. The whole procedure is well adapted to automatic straight line production. Laboratory results show that one pound of water may be removed electronically with less than one kilowatt hour of energy, a figure which is economically good in comparison with other methods.

In addition to the above mentioned vegetables, dried whole milk also has had its moisture content reduced electronically from two per cent to one per cent. This small difference makes it possible to ship dried whole milk without danger of its butter fat content becoming rancid. Unlike dried skim milk, dried whole milk can be reconstituted to be as palatable and nutritious as fresh milk.

Aside from the importance of this electronic dehydration achievement, the results of which are especially timely in connection with the transportation of food abroad, it is interesting to note that the process represents another of the many outgrowths of fundamental research and development in industry. Electronic dehydration of food stuffs was undertaken by the Federal Corporation as a cooperative and non-remunerative project to aid in the war effort.

Thin Case Hardening with Radio-Frequency Energy

By VERNON W. SHERMAN,* Member A. I. E. E., Member A. S. M.

Federal Telephone and Radio Corporation, Newark, New Jersey

Distortionless thin case hardening with radio-frequency energy makes possible the finishing of parts to final dimensions prior to heat-treat. Uniformly hardened cases 0.005 to 0.030 in. deep, controllable to within ±0.001 in., have been produced using 5 megacycle energy. Photographs of applications show the heat-treating process as applied to the outside diameter of cylindrical surfaces, the inside diameter of tapped bolt holes, and the flat edge of a slide plate. For most heating processes the 5–15 megacycle range of frequency is recommended by the author. It is shown that in order to produce thin hardened cases two fundamental energy requirements exist: (1) the frequency should be in the megacycle range so that the induced energy is confined to a thin surface layer; (2) power must be applied to the surface of the work at not less than double the rate of heat conduction loss from the surface to the core.

Macro- and microphotographs show that the thin cases produced with megacycle energy are homogeneous and uniform. The transition from case to core takes place smoothly and in a short distance compared to the case thickness. Because of the speed with which the surface layer is heat-treated, no measurable tempering action was found to have occurred in the adjacent core layer. The case was found to be under compression, but because of its relative thinness the total force was negligible. A mathematical expression is given which has been found to express the temperature after a time t of a point located a distance x beneath a heated surface. The expression involves constants that may require reinterpretation if the geometry of the part is appreciably changed. By use of the expression a set of curves is developed showing a temperature distribution that is in good agreement with experimental evidence.

Preface

THE discussion of thin case hardening with radio frequency falls logically into two major divisions and the subject is accordingly divided into: (1) the consideration of energy requirements, temperature distribution, and metallurgical results; (2) the consideration of factors controlling the distribution of electrical energy in the surface of steel being heated by radio frequency current.

The present paper (1) is concerned with induction heat-treating in the 1–20 megacycle frequency range. It is further restricted by the proposition that an induction heating process should be able to establish a thin case of hardened metal on the surface of a hardenable steel without distortion of the part, scaling of the surface, or disturbance of any prior heat-treat already established in the core. By a thin case is meant one between 0.005 and 0.030 in. This case thickness should be controllable to within ±0.001 in. and should be capable of reliable duplication in quantity production. The author will attempt to show that the time required for establishing the case should not exceed 1.0 sec. Examples will be given wherein thin cases were produced in times ranging between 0.6 and 1.0 sec. For this class of heat-treatment a frequency above 1 megacycle and available power output of 25–75 kw. was commonly required.

Background

Induction heating of metals is not new. The earliest electrical experiments indicated the possibilities. Before the turn of the century a good many patents concerned with this field had been issued both here and abroad. In 1890, Colby was issued a U. S. patent for an induction melting process. His application was filed in 1887. Colby showed a rotating generator as a source of alternating or pulsating electrical energy, a current transformer with a core of soft iron wires electrically insulated from each other, and a low impedance single turn secondary in the form of an annular trough to hold the melt. He also pointed out that in the case of conducting metals the furnace melt or charge could constitute the

* Paper presented at the Materials Session, Eleventh Annual Meeting, Institute of the Aeronautical Sciences, New York, January 27, 1943.

entire secondary circuit. Nikola Tesla, writing in the *Electrical Engineer*, 1898, describes in some detail an early use of Hertzian Waves for induction heating. This work was of an experimental and pseudomedical nature, but regardless of its practicability it makes fascinating reading. Tesla used a spark coil oscillator. In 1925 a U. S. patent showing vacuum tubes as a source of energy for induction heating apparatus was issued.

Induction Heat Frequency

Just as frequency converters for radio communication purposes have gone through an evolution from rotating machinery, to spark gaps, to high-power vacuum tubes, so we can trace a similar pattern, but in a much briefer time, for the induction heat-treatment of metals. The power vacuum tube has earned its place in the field largely through years of painstaking and thorough development which has made it the key piece in modern broadcasting.

All of the frequency converters mentioned are reliable. There is, however, a range of frequency best suited to each converter, and this fact leads naturally to a grouping of induction heat equipment according to the frequency used. Fig. 1 gives a logical grouping and indicates the particular frequencies most commonly used in each group.

To summarize the chart of Fig. 1, the principal frequencies in use at the present time for commercial melting, preheating, and annealing are, in general below 12,000 cycles. For surface hardening of relatively large parts where considerable depth of case can be permitted, even frequencies near 12,000 are of value. For thin case hardening (0.005–0.030 in.) frequencies above 500,000 cycles are indicated. For most heating applications the author recommends 5,000,000–15,000,000 cycle energy, and even special requirements seldom lie outside 1,000,000–20,000,000 cycle energy.

Versatility

The versatility of induction heating equipment increases cumulatively with the frequency used. For example, 5 megacycle energy can, in addition to melting, annealing, etc., also produce thin surface hardening without disturbing a prior heat-treat of the core. The same 5 megacycle energy can also be used for drying paper, bonding plywood, softening thermoplastics, and many other operations in the dielectric heating field.

Cost of Energy

The energy cost of induction heat at a frequency other than commercial 60 cycle carries a cost penalty. The penalty is due to the frequency conversion means and not to the frequency itself. It is important to note that the efficiency of

60* 180* 360* 1,000	2,000* 9,600* 12,000	50,000 200,000	450,000* 5,000,000* 15,000,000* 100,000,000
Preheating, annealing, or melting of magnetic material by direct induction and of nonmagnetic material indirectly.	Melting, brazing, and general heat-treat — deep and approximate surface treatment with 9,600.	Melting, brazing, and general heat-treat—limited surface treatment dependent upon power and frequency.	Controlled depth surface heat-treat. Vacuum melting. Accurate zone heating for hardening, brazing, or silver soldering. Sustained heating beyond magnetic critical. General heat-treat of both magnetic and nonmagnetic materials.
			Electrostatic heating as in bonding of plywood, thermosetting of plastics, dehydration processes, etc.
Rotating alternator up to thousands of kw.	Rotating alternator up to 1,200 kw.	Spark gap oscillator up to 35 kw.	Vacuum tube oscillator up to 600 kw.

* Frequencies most generally used.

Fig. 1—Induction Heat Frequency Spectrum—Use and Power.

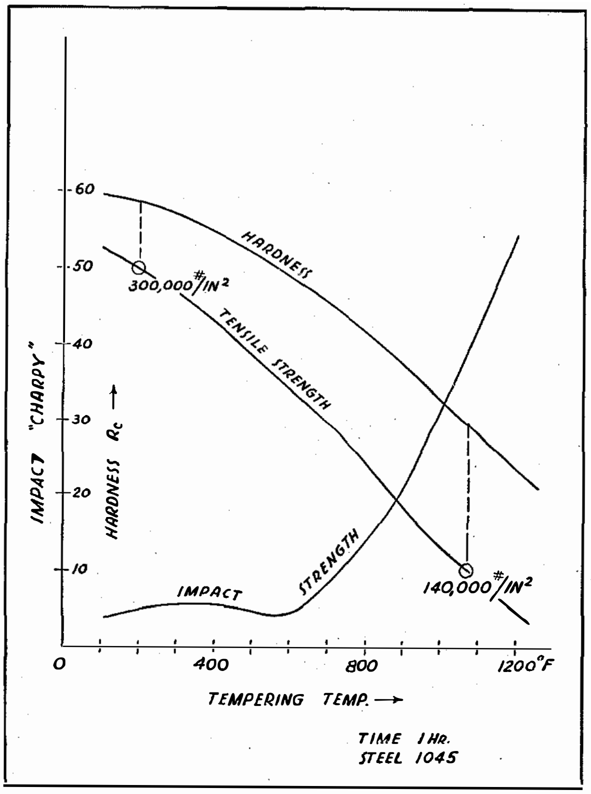


Fig. 2.

frequency conversion with vacuum tubes can be as high or higher than that of lower frequency means. Depending upon the efficiency of the equipment, heating energy may cost from 3 to 6 cents per kilowatt hour as compared to a 60-cycle base cost of 2 cents.

General Considerations

In the field of heat-treating a desirable result has long been the creation of a hard skin over a tough interior. Fig. 2 shows two conflicting curves that picture rather well the dilemma in which the metallurgist frequently finds himself when he is faced by the simultaneous requirements of hardness and toughness from the same heat-treat. Fig. 2 shows that a steel quench-hardened throughout to 60 Rockwell C may have to be drawn back to 35 Rockwell C before its toughness is satisfactory. The author will attempt to bring out in this paper what is considered to be an ideal solution to the problem and one that will allow the metallurgist to "have his cake and eat it too." The problem is that of retaining a desired internal toughness at the same time a surface hardness is created.

In general, "surface heat-treatment" has had two practical faults: (1) The heat has penetrated too deeply and (2) the penetration was frequently

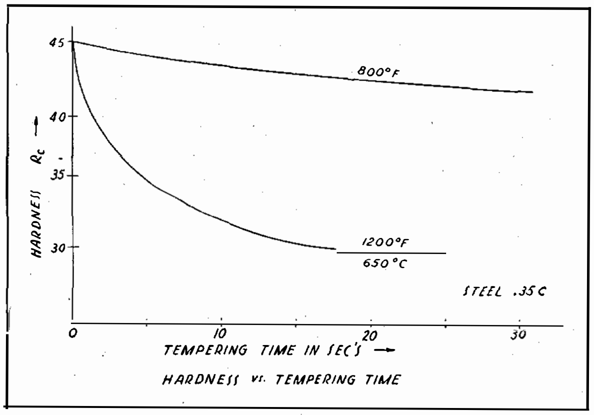


Fig. 3.

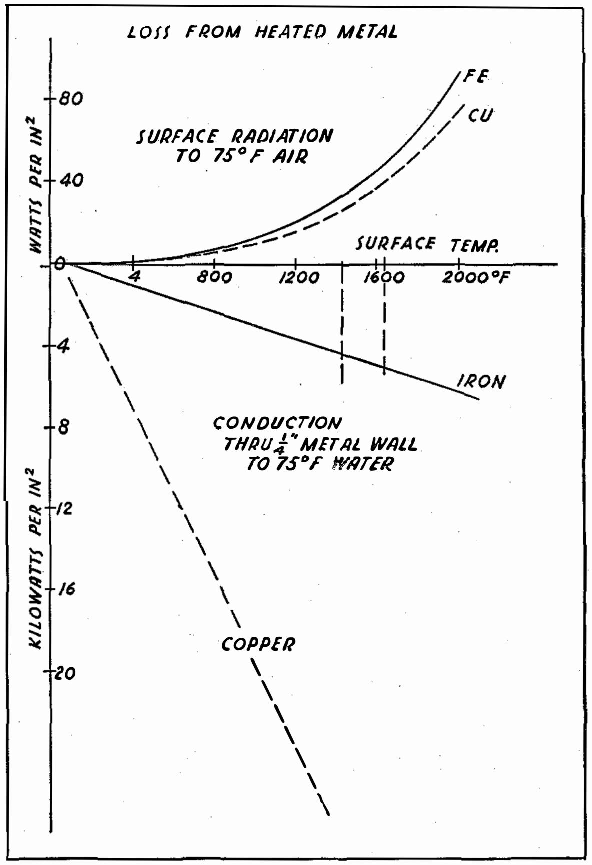


Fig. 4.

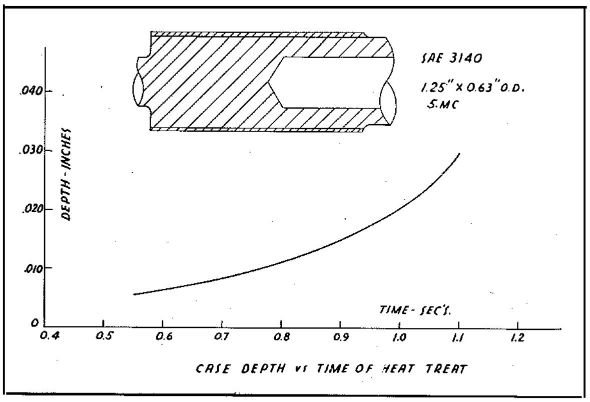


Fig. 5.

far from uniform. These have commonly been due to either too low a frequency or a slow heating rate which made it necessary to maintain treatment for a considerable period of time, such as 15 sec. or more.

With a surface temperature of 1,600° F., the loss of surface heat by natural conduction to a 75° F. layer ¼ in. beneath the surface is at the rate of approximately 5 kw. per sq. in. of surface, as shown by Fig. 4. The transfer of surface heat to the interior is a function of time and of temperature difference between the surface and the interior. It decreases only as the interior becomes hotter and it therefore follows that, if heating of an interior layer by the surface temperature is to be prevented, the heating power must be equivalent to several times the conduction loss and the time of treatment must be kept short enough to minimize conduction drastically. Heat conduction is the number one obstacle to uniform case hardening. Heat is generated in a controllable depth of case, but the heat flow to the interior will be determined by the configuration and thermal properties of the part and may well be out of our control. Since there is usually no excuse for hardening to a depth much in excess of allowable future wear, it seems that the cost of heat-treat energy and time is only justified in a layer some 0.010 to 0.030 in. deep. In applications where impact load or high unit stress is the criterion, somewhat thicker cases may be required.

Solution of Carbides

The time required for carbides to go into solution seems to be extremely short. It has been experimentally true in laboratory work that whether the steel were a plain carbon type or an alloy steel no difficulty was encountered in putting the carbides into solution and securing just as hard a case in a fraction of a second as could be had with longer treatment by standard furnace procedure. It appears that the rate of heating of the steel is independent of its chemical composition, except insofar as that composition may affect electrical or magnetic properties. It is possible that with induction heating the higher resistance of undissolved carbides actually results in abnormally high temperatures in and near such carbide inclusions which promote especially rapid solution of the carbides.

Hardenability

The hardenability of the steel under the high-speed radio-frequency process appears to obey the relations to chemical composition as set forth in M. A. Grossman's excellent treatise on the subject.

Distortion and Scaling

In certain hardening work the prime objective may not be surface hardening as such. It is often important for economic reasons to prevent distortion and scaling of the part so as to eliminate or to drastically minimize grinding costs. The essence of this problem lies in producing a uniform thin case so that the interior metal will still retain ample strength to hold its original shape. Freedom from scaling or severe oxidation can be secured through reduction of time just as readily as it can through reduction of temperature. When the heat-treatment is completed in a second or less, there is no scaling of the surface, even in ordinary atmosphere. This time is barely sufficient to create a blue oxide color. It is, of course, thoroughly practical when using radio-frequency energy to conduct the heat-treating in a controlled atmosphere, such as hydrogen, and thus prevent oxidation.

Subnormal Strength Layer

There is a possible consequence of surface heat-treating which is of considerable interest. This is the danger of creating just beneath the hardened layer a second layer of subnormal strength. Consider as an example a steel axle shaft that has, for purposes of best physical properties, been heat-treated throughout to a hardness of 33 Rockwell C. To satisfy a bearing application, next surface-harden a deep layer, perhaps ⅛ in., over a portion of the shaft's surface. If in so doing the temperature of this ⅛ in. surface layer is raised to 1,700° F. and held there for 30 sec., it is obvious that a second layer in direct contact with the surface layer may experience tempering. The thickness of this tempered layer will depend upon the temperature and the time of drawing. Once this time has elapsed a helpless position results, since not only has considerable heat been stored within the body of the part which will retard the quenching of the surface but this same stored heat promotes further tempering of the second layer. If the second layer loses hardness by tempering, it will, in general, also suffer a loss of tensile strength, as indicated by the curves of Fig. 2.

Control of Tempering

The amount of tempering is a function of time and temperature. Temperature has been fixed by the requirements of the job. Fig. 3 shows that most of the softening action occurs in the first few increments of time and that for a given temperature the tempering action decreases logarithmically with time. Thus, the loss of hardness for a 10-sec. time interval between 10 and 20 sec. would be substantially the same as the loss during a 100-sec. time interval between 100 and 200 sec. of total tempering time. The curves shown are for a particular carbon steel only. Fig. 3 teaches that if tempering is to be prevented, action must be taken during the first few seconds.

Electrical Energy Requirements

When an iron cylinder is placed within the turns of an induction heating coil energized with alternating current, heat is developed in the iron part. It has already been noted in a general way that a high rate of energy input for a short time interval is required to restrict heating to a controllable surface layer. The relationship between rate of heating and the electrical energy required to produce it will next be considered.

Process of Heat Generation

When the turns of the induction heating coil enclose an iron cylinder, a transformer is created whose secondary is the short-circuited surface layer of the iron cylinder. The current I which is induced into this secondary flows through a resistance R and develops heat at a rate that in watts is equal to I^2R. This is the mechanism whereby electrical energy is converted into heat energy.

In a particular induction heating coil there will be a finite number of turns, such as ten, and through these turns the equipment will drive some definite current, such as 100 amp. There is then available for heat-treating purposes a 1,000 amp.-turn primary. Since the secondary consists of one turn, its theoretic maximum current cannot exceed 1,000 amperes.

Coupling Factor

Because of the need for insulation, mechanical clearance, etc., the secondary will be spaced somewhat away from the primary and therefore not all of the primary flux will thread the surface of the work. If only 50 per cent of the primary flux links with the surface of the work, then the coupling factor is 0.5 and only half the primary ampere-turns, or some 500 amp. in the one turn secondary circuit, are available for generating heat in the work. Since the heating rate in watts equals I^2R and since the current has already been determined by the primary ampere-turns and the coupling factor, it follows that the rate of heating in the metal can only be increased by increasing the resistance of the surface layer in which the current is confined.

Resistance Versus Frequency

It will be shown in a later paper that the thickness of the layer in which the current is confined varies inversely as the square root of the alternating current frequency. Accordingly, if the operating frequency is increased from 1 megacycle to 4 megacycles, the thickness of the current-carrying surface layer is reduced to one-half. Therefore, the secondary resistance through which the 500 amp. must flow is doubled, and the heat developed in the surface layer by this current is also doubled. At the same time, the

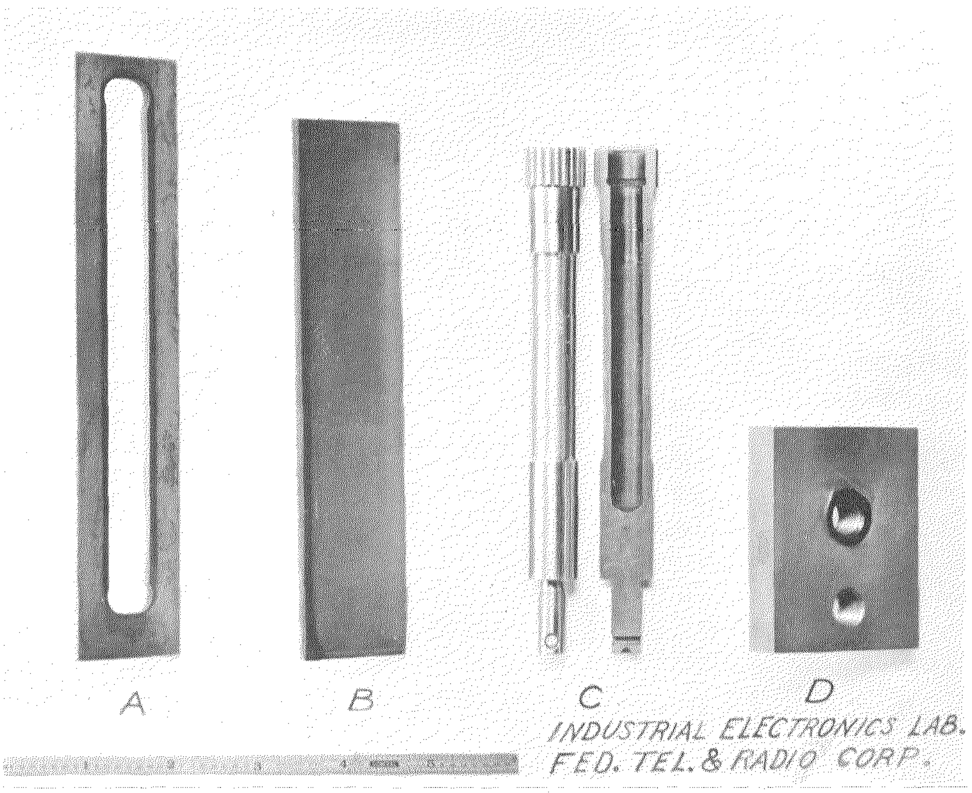


Fig. 6.

heating current has been restricted to half of the depth it occupied at the lower frequency. The problem of keeping the resistance high by means of a thin surface layer is of increased importance as the diameter of the work becomes smaller. For example, if the work were ¼ in. outside diameter as compared with 1 in. outside diameter, the resistance of the current-carrying path would be only 25 per cent of that of the larger piece.

The above example brings out a fundamental reason for high frequency in surface hardening. There will always be a frequency converter of limited output; an induction heating coil with a limited current-carrying capacity; a finite number of turns; and, last, a coefficient of coupling between the work and the coil whose value for practical design purposes is also fixed. All the above restrictions will limit the magnitude of the secondary current. There remains only the control of the secondary resistance by exploitation of high-frequency skin effect.

Loss from Heated Metals

The rate of loss of energy from a heated metal surface, both to air and to a 75° internal layer, is plotted in Fig. 4. Two representative metals, iron and copper, are considered. The curve shows, for example, that the rate of energy loss from a 1,300° F. surface of iron to an internal 75° F. layer that is located ¼ in. below the surface will be some 4,000 watts per sq. in. It is also seen that while 4,000 watts of energy leave the surface by conduction to the interior only 25 watts of energy are being lost by radiation to outside air. It thus appears that for all practical purposes the radiation loss is negligible as compared to the conduction loss. The curves of Fig. 4 bring out a second fundamental heating requirement—namely, that in surface hardening the conduction loss at the temperature in which there is interest sets a minimum heating rate requirement in kilowatts per square inch. Unless electrical energy can be supplied from the induction heating unit at a rate at least double that of the conduction loss, it is not reasonable to expect much better than nonuniform deep heating of the work which would upset any previous heat-treat of the core.

Watts per Square Inch—Example

Just how much electrical energy per square inch must be supplied beyond that dictated by the conduction loss depends upon the temperature that can be tolerated at particular depths beneath the surface. It has been found that by applying electrical energy at a high rate, a 0.007-in. layer can be hardened to 60 Rockwell C without effecting a prior heat-treat of the parent metal. To accomplish this required three times more energy per square inch of surface than the conduction loss. It also required a frequency near 5 megacycles and a time of 0.6 sec. The relation between time of heat-treat and hardened case thickness for a fixed power output is plotted in Fig. 5.

Cost of Energy—Example

Analysis of the associated operating data shows that when the heating energy is restricted to the vital layer operating costs are drastically reduced. As an example, consider in Fig. 5 the 0.020-in. case, which required 1.0 sec. of heat-treat. The surface area was 2.25 sq. in. The full load line power was 63.6 kva. The no load line power was 15.6 kva. With an assumed load cycle of 50 per cent (i.e., 1 sec. "on" and 1 sec. "off") and an electrical energy cost $0.02 per kwh., it is noted that the unit has a capacity of 1,800 pieces, or 4,500 sq. in. per hour, and that 23 pieces have been case hardened or some 52 sq. in. of surface for each cent's worth of electrical energy. It is important at this point to note that if it had been required to heat the entire piece operating costs would have been increased some 500 per cent.

Metallurgical Results

The author feels that before the metallurgical aspects of thin case hardening with radio frequency can be intelligently discussed it will be necessary to analyze test findings in a broad and diversified field of applications. The reaction thus far obtained from competent metallurgists has been that in many respects the structure is difficult of analysis and that the appearance of the microphotographs should not be interpreted entirely in the light of microphotographs resulting from slower speed methods of heat-treating. The author will therefore confine his remarks largely to the presentation of photographs and test data.

Examples

Some of the hardening operations possible with radio-frequency energy are represented in Fig. 6. Part A is a slotted guide plate shown as an example of surface hardening of straight flat surfaces. The plate is 1/8 in. thick and has two parallel guide faces 5 1/2 in. long separated by a distance of 1/2 in. The parent metal had a hardness of 20 Rockwell C and the surface hardness of 55 Rockwell C was created in 0.9 sec. The surface was self-quenched. No external coolant was used. Part B is a strip of 1/8-in. steel that has had one edge only hardened. This is similar to part A but shows the additional fact that it is not essential for the work surface to form a closed loop. Part C is a certain shaft upon which two bearing journals were to be surface hardened. This shaft example was the most difficult of those shown, due to the fact that it has a nonuniform interior cross section. Because the wall thickness in the hollow portion is only 1/8 in., this shaft was selected for the paper as a good test example of thin case hardening with radio frequency. Part D is a 3/8 in. inside diameter tapped hole and illustrates that inside surfaces of small areas can be heat-treated with radio frequency energy at speeds sufficiently high to permit self-quenching of the surface.

Macrophotographs

Fig. 7 shows a longitudinal cross section of the shaft after its bearing surfaces were hardened with radio-frequency energy. It will be noted

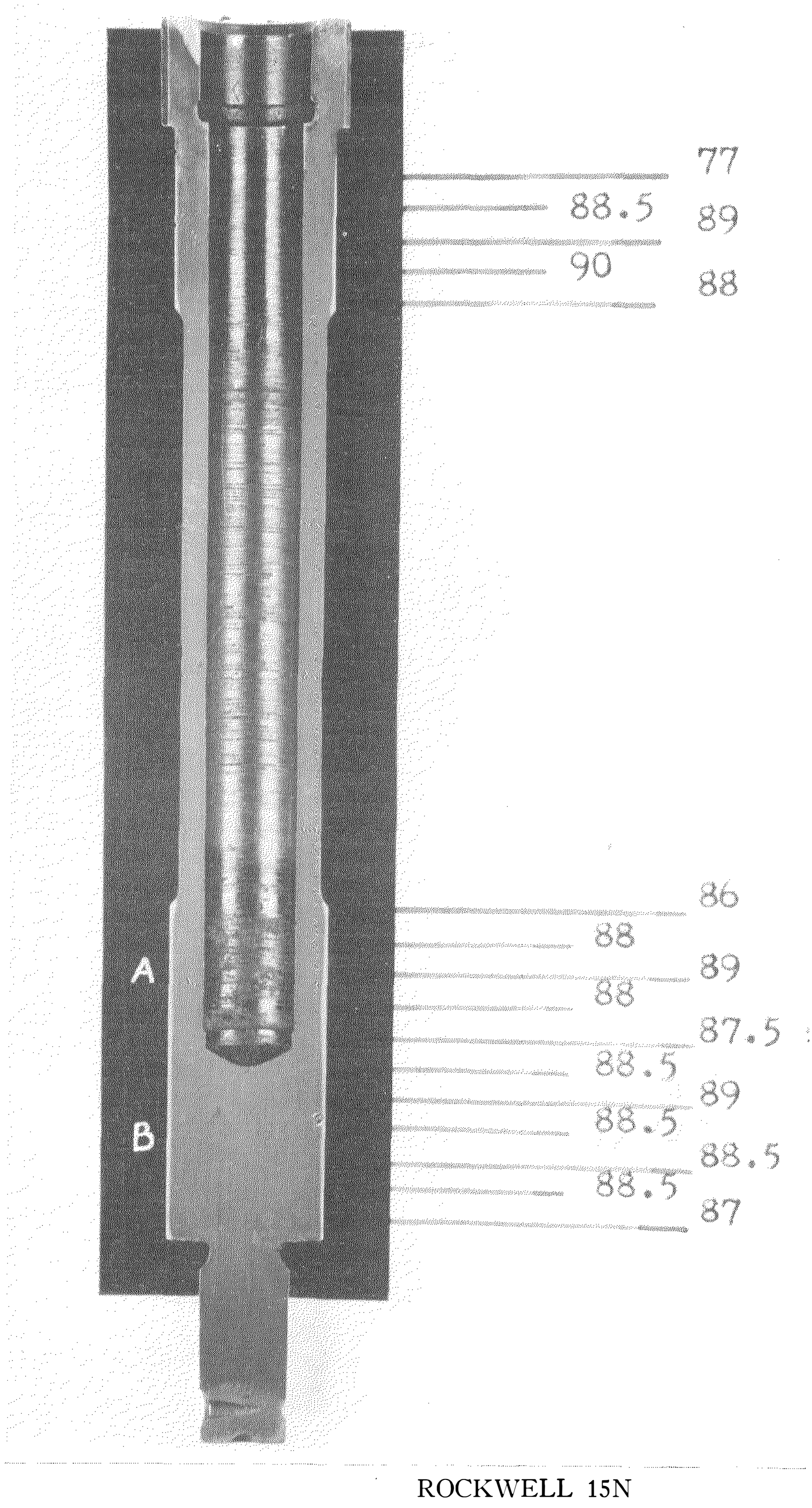


Fig. 7—Macrophotographs: (Left) Cross Section Shaft 1.4×.

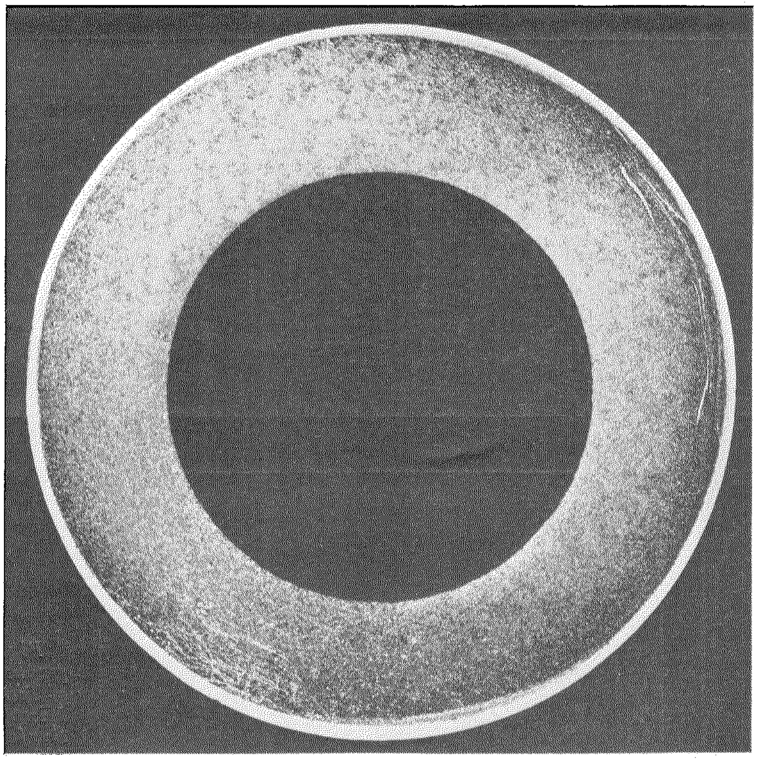
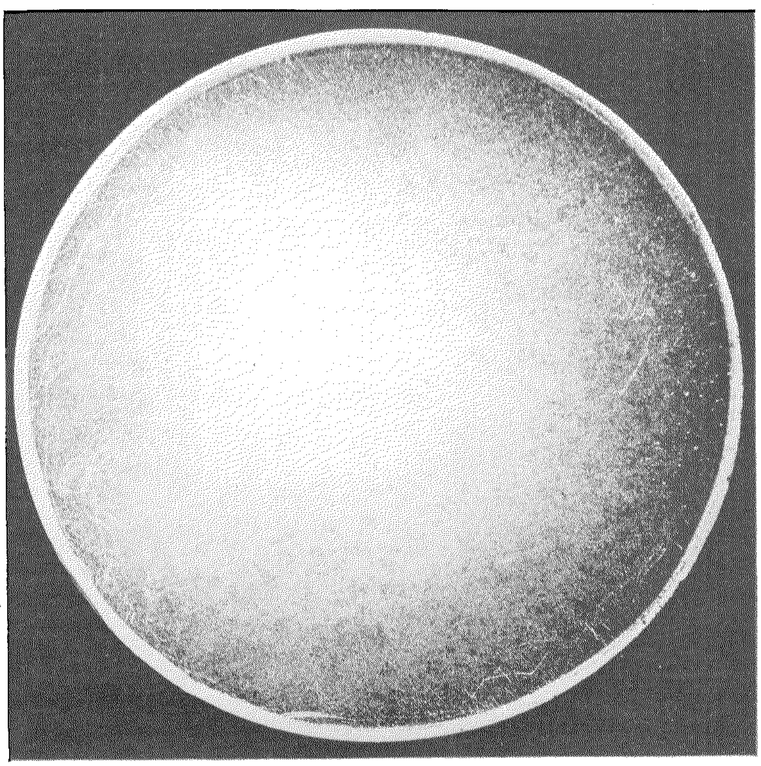


Fig. 7—Macrophotographs: (Upper) Section A 6×; (Lower) Section B 6×.



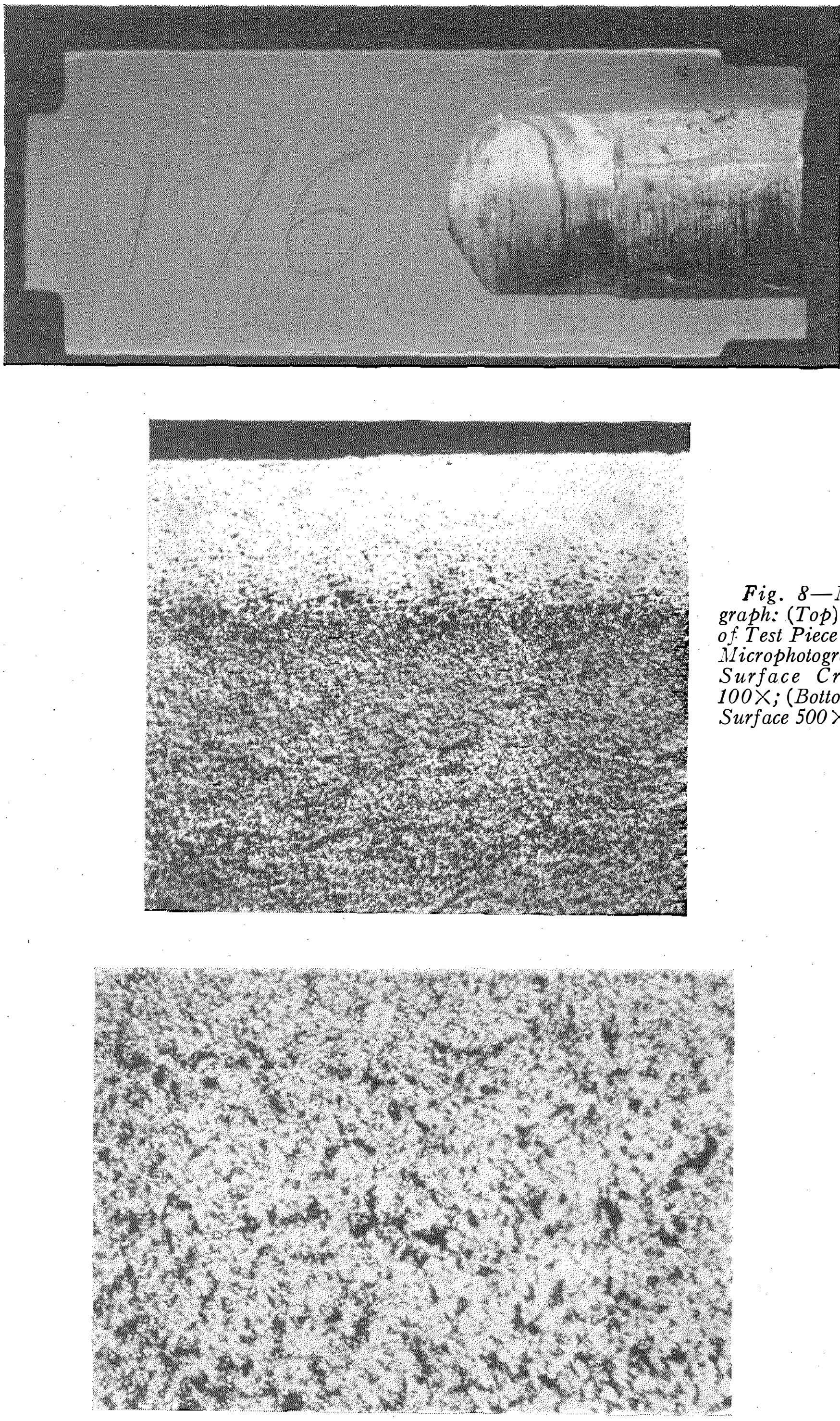


Fig. 8—Macrophotograph: (Top) Cross Section of Test Piece No. 176 3×; Microphotographs: (Center) Surface Cross Section 100×; (Bottom) Case Near Surface 500×.

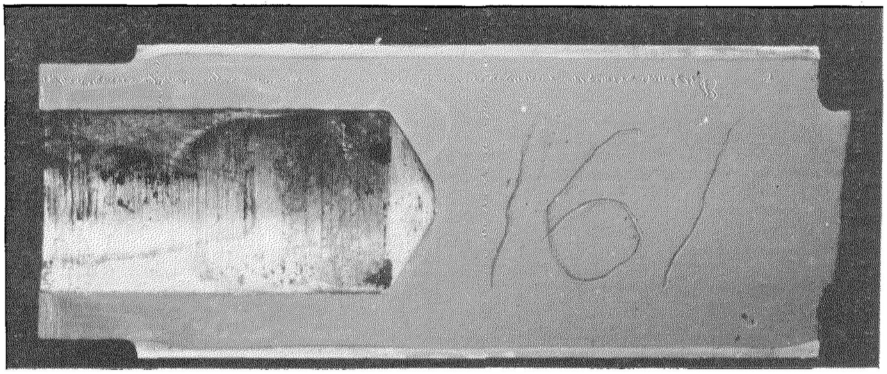
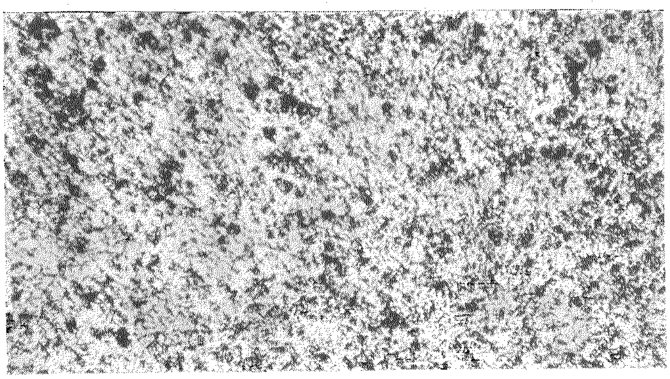


Fig. 9—Macrophotograph: (Top) Cross Section of Test Piece No. 161 3×; Microphotographs: (Center) Surface Cross Section 100×; (Bottom) Case Near Surface 500×.



that the shaft had been drilled out prior to heat-treat so that a portion of the lower bearing has a wall only ⅛ in. thick, as at section A, whereas at section B the shaft is solid. Macrophotographs of cross sections taken at position A and position B from a similar shaft are shown. It will be observed that in spite of the difference in depth of parent metal beneath the surface to be hardened the surface layer developed by radio-frequency energy is uniform.

The upper bearing case is substantially uniform over some 80 per cent of its length and near the upper end tapers away to zero thickness. The reason for the taper is that a necessary compromise had to be made at this part of the shaft because of the proximity of a spline whose prior heat-treat could not be disturbed. It is interesting to note that although the upper bearing's case depth has tapered at one end the hardness readings remain reasonably uniform almost to the vanishing point of the case. Hardness readings shown are from Rockwell 15N scale where 88 corresponds to 55 Rockwell C.

Case Depth Versus Heat-Treat Time

It was found that the depth of the case developed on this shaft could be controlled to within ±0.001 in. and that for the particular power used its relation to heat-treat time was as shown in Fig. 5. It will be noted from Fig. 5 that the relationship between depth of case and elapsed time of heat-treat is approximately linear up to 1.0 sec. but that as the heat-treat time increases to 1.1 sec. a sharp upturn develops in the curve. Beyond 1.0 sec., small increases of time result in considerable increases in depth of case. This was interpreted as meaning that the temperature gradient between the surface and interior points has become too flat to remain controllable from the surface.

Distortion and Scaling

Because there was no distortion and oxidation was negligible, both the upper and the lower bearing surfaces were thin case hardened *after* having been finish ground to *final dimensions.* During the development work a considerable number of these shafts were carefully checked before and after heat-treatment to establish that no distortion or warping occurred.

Surface Forces

High-speed hardening of a surface layer by induction heat will leave the surface under compression. If the surface layer were thick, the force exerted by this stress would be important, but with thin case hardening the force is negligible. For example: a ⅛-in. square annular ring cut from a shaft, as in Fig. 7, position A, was carefully measured before and after cutting through one side. After cutting the ring closed in slightly but the change in outside diameter was only 0.0013 in. out of 0.630 in.

Microphotographs

Detailed examination of cases developed at depths of 0.009 and 0.020 in. are shown in Figs. 8 and 9. The longitudinal macrosections of test piece 176 and 161 are 3X and show reasonably well the uniform case developed along the lower bearing surface. They also show the relative depth corresponding to their heat-treat times of 0.7 and 1.0 sec., respectively. The microphotographs of a longitudinal cross section extending from the case through the core show how sharp and definite the transition is from the 30 Rockwell C hardness of the core to the 55 Rockwell C hardness of the case. At the bottom of Figs. 8 and 9 there are shown 500X micro-

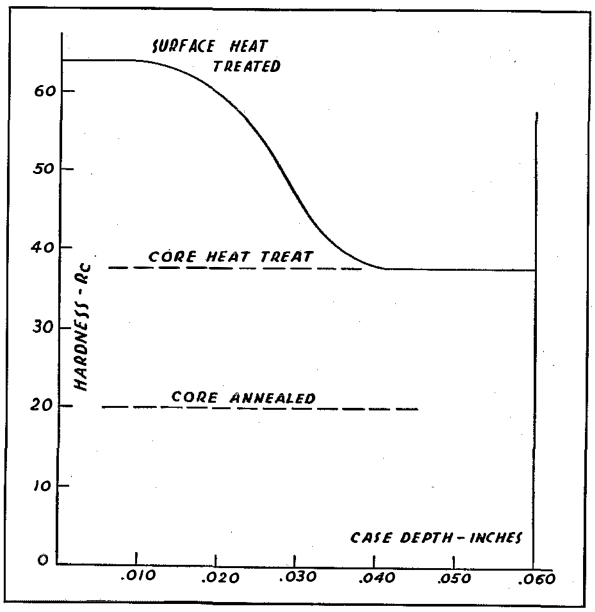


Fig. 10.

photographs of the hardened surface layers taken near the outside edge.

Tempering by Surface Layer

The possibility of a subnormal strength layer having been created by tempering action of the heated surface layer was of considerable interest. The appearance of the microphotograph seemed to indicate that some tempering had taken place. This seemed dubious because of the short time involved. Examination across the case boundary layer with a Vickers hardness tester has thus far failed to disclose any loss of core hardness. Fig. 10 shows a plot of case hardness as a function of depth beneath the surface and it will be noted that it did not dip below 30 Rockwell C. The material, before the original heat-treat, had a hardness of 20 Rockwell C. It is not intended that this limited evidence should be accepted as conclusive. The author has incorporated it only as representing his best present knowledge of the situation. In connection with this same point, it may also be of interest to mention that the point-to-point Vickers test was supplemented by a constant pressure scratch test, wherein a sapphire point was drawn across a polished section so that its track width might be observed under a microscope as an indication of relative hardness in the core, the boundary layer, and the hardened surface. No tests thus far show evidence of the boundary layer having become tempered by the surface heat. Test work along this line of attack is still in progress.

It was mentioned above that microphotographs of high-speed heating results should be cautiously interpreted. An example in point is contained in the two 500X microphotographs of the surfaces shown in Figs. 8 and 9. It will be observed that considerable difference exists in the surface structure indicated for the two depths of case shown. However, the two cases had identical hardness as measured by either Vickers or by Rockwell 15N. It may also be observed by metallurgists that these microphotographs show minute quantities of undissolved carbides in the hardened surface layer. This is a point of considerable academic interest and may ultimately lead to more precise knowledge regarding the minimum time and temperature conditions required for carbides to go into complete solution. The question is beyond the scope of the present paper, which has been concerned only with establishing the fact that thin, accurately controlled cases can be created on the surface of hardenable steels with radio-frequency energy.

Temperature Distribution

In the field of surface heating it is of fundamental importance that we know as much as possible about the temperature distribution in the work. The ideal would be an equation that would express the temperature of any particular point as a function of surface temperature, time of heat-treat, and distance from surface. A useful equation applied by Dr. S. Frankel is one based on flat plate unidimensional heat flow:

$$u=u_0\left\{1-\frac{4}{\pi}\sum_1^n \sin\frac{\left(\frac{(2n-1)\pi x}{2\tau}\right)}{2n-1}\cdot e^{-\frac{(2n-1)^2\pi^2 t}{4c^2\tau^2 k}}\right\}$$

Expanded, the equation becomes

$$u=u_0\left\{1-\frac{4}{\pi}\left[\frac{\sin\frac{\pi x}{2\tau}}{1}\cdot e^{-\frac{\pi t}{4c^2\tau^2 k}}\right]-\frac{4}{\pi}\left[\frac{\sin\frac{3\pi x}{2\tau}}{3}\cdot e^{-\frac{9\pi^2 t}{4c^2\tau^2 k}}\right]-\frac{4}{\pi}\left[\frac{\sin\frac{5\pi x}{2\tau}}{5}\cdot e^{-\frac{25\pi^2 t}{4c^2\tau^2 k}}\right]-\cdots\right.$$

where u = temperature of the point in question
u_0 = surface temperature
$C^2=\dfrac{\text{specific heat}\times\text{density}}{\text{specific conductivity}}$
k = empirical constant = heat distribution correction
τ = total wall thickness
x = distance of point from surface
t = time in seconds
e = 2.718

The equation expresses the internal point temperature in the form of a converging series. Solving for the first term only will in most cases be sufficient.

Proper use of the equation requires accurate knowledge of the surface temperature versus time relation since the equation itself was derived for suddenly applied fixed values of surface temperature. Fig. 11 shows actual surface

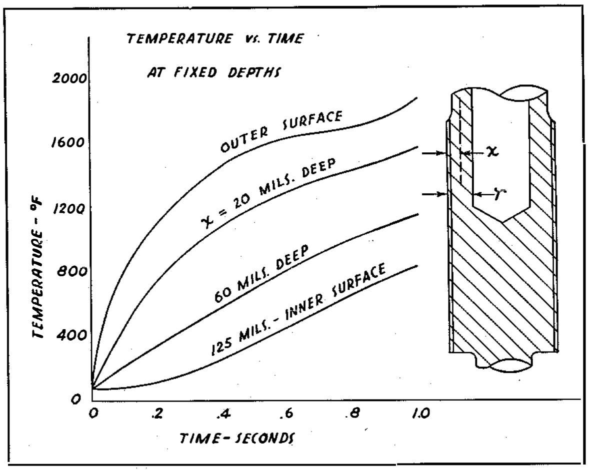


Fig. 11.

temperature versus time for a particular case hardening job.

The evaluation of c^2 and k is rather involved, since the determining factors vary with surface temperature and with temperature distribution. It will be sufficient for purposes of this paper to give only the results of the calculations. These are summarized in the curves of Fig. 11 and Fig. 12. The curves apply to the wall over the hollow portion of the shaft, as at position A of Fig. 7.

Fig. 11 shows the temperature versus time for the surface layer as compared to that of particular layers located at various depths beneath the surface. The curves shown apply only to a particular part for which the outside diameter was 0.630 in., the wall thickness (τ) was 0.125 in., and the rate of power input to the surface of the steel was 15 kw. per sq. in.

Fig. 12 shows the data of Fig. 11 replotted to show temperature versus depth at a particular time. This derived form of the data is of more direct interest, since it indicates the required heat-treat time for a particular case depth and hardening temperature. Although Fig. 12 applies specifically to the job and power mentioned, it is broadly representative of the general case.

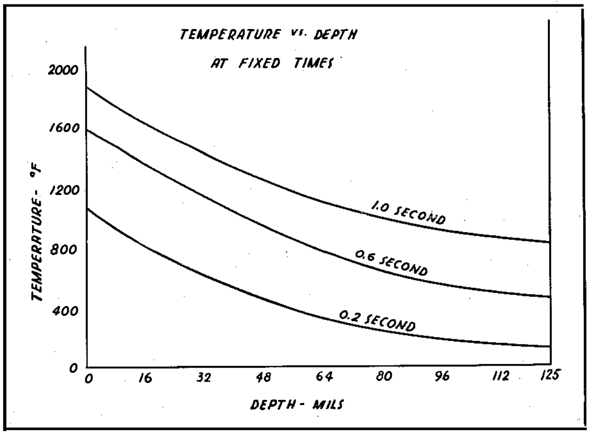


Fig. 12.

Conclusion

The author has attempted to show that megacycle energy is a prerequisite for uniform thin case hardening. It was shown that, by restricting heat to the surface layer of the work, increased speed and lower energy cost resulted. Freedom from distortion or warpage of the work was directly associated with high-speed thin case hardening. This fact, together with freedom from scaling, made final machining prior to heat-treat feasible. Since the heat gradient between surface and interior is high, self-quenching of the surface is usually possible and will result in a saving of space and equipment. The space requirement of a vacuum tube oscillator is small. Its power supply can be located at a remote point, and its work load can be either located at the oscillator or coupled to it from a distance by means of a grounded concentric line. Many parts of nominal size can be made fully automatic as to loading, heat-treating, and ejection. The possibility of the heated surface layer tempering an adjacent interior layer and thus reducing its tensile strength was investigated. No measurable loss of hardness was found. This was attributed to the short time during which the interior layer had been exposed to high temperature. The temperature distribution curves for a particular piece which were shown illustrate that, unless the heating time is restricted to 1.0 sec. or less, interior layers will reach undesirably high temperatures.

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