LB-1033

FIELD-INTENSITY MEASUREMENTS ON INDUCTION-HEATING EQUIPMENT

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Approved

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This bulletin describes the program undertaken at RCA's Lancaster, Pa. plant to minimize and measure radio-frequency radiation from a large number of induction-heating equipments in order to assure compliance with FCC regulations. The Lancaster plant is a complex radiating source containing more than 100 separate installations operating at various frequencies between 150 and 1500 kilocycles and producing harmonics up to 15 megacycles. The program, which required the better part of two years to complete, consisted of three main steps: (1) determination of the magnitude of the radiation; (2) modification of equipment to reduce radiation to an acceptable level as prescribed by FCC requirements; (3) the actual certification measurements.

During the course of this program, methods were developed to ensure constant operation of the equipments during the tests, to reduce the measuring time, to locate the causes of radiation from a particular installation, to record the data, and to change the frequency of an installation so that its radiation could be identified and measured.

As a result of this program, only one unit radiated as much as 7 microvolts per meter at a distance of one mile. Radiation from most installations cannot be detected beyond 2000 feet from the plant.

RF induction heating is used extensively in electron-tube manufacturing as a means of degassing tube parts during exhaust, flashing internal "getters," for brazing, and for glass-to-metal sealing. The frequencies which have been found most suitable for these applications lie in the range between 150 and 1500 kc, and consequently are outside the channels assigned for induction-heating service by the FCC[1]. The use of induction-heating equipment operating at these frequencies is permitted, however, provided the strength of any radiations at fundamentals or harmonics does not exceed 10 microvolts per meter at one mile or more from the equipment. Certification of compliance with this requirement must be made, and a copy of such certification posted in the immediate vicinity of the equipment. Originally, individual certification for each unit of equipment was required. Under present regulations, however, a single certification may be made for all induction-heating equipment located within an area having a radius of 500 feet or less, provided the radiation is 10 microvolts or less at a distance of one mile less the radius of the enclosing circle.

The FCC regulations relating to Industrial, Scientific, and Medical Service specify the measurements required for certification of induction-heating equipment and the data which must be included in the posted certificates. They also require that all measurements be made using approved-type Field-Intensity Meters equipped with loop antennas.

This bulletin describes the program undertaken at the RCA Lancaster, Pennsylvania tube plant to assure compliance with these requirements. This program involved three major steps: (1) a preliminary survey to determine the magnitude and frequency characteristics of the existing radiation field; (2) modification of equipment where necessary to reduce radiation below the authorized maximum value; (3) actual certification measurements.

The RCA Lancaster plant is a complex radiating source containing approximately 100 induction-heating installations operating at various fundamental frequencies between 150 and 1500 kilocycles, and producing harmonics up to 15 megacycles. The power outputs of these units range from 1 to 10 kilowatts.

Typical of the installations at Lancaster for which certification was required is a 24-head vacuum-tube exhaust machine equipped with induction-heating facilities at eight of its exhaust positions. These facilities consists of individual work coils connected in series and

supplied by a self-rectifying oscillator capable of delivering an rf current of up to 200 amperes rms. Since coils must be raised above the tubes during intervals when the machine "indexes" (rotates from one exhaust position to another), they are mounted on an elevator boom and connected to the line from the rf generator by means of flexible leads. If the coils, leads, and shields employed in this circuit are not properly installed and grounded they form a loop capable of radiating signals well in excess of FCC limits. The radiation contains a very strong 120-cycle modulation component resulting from the use of a self-rectifying "push-push" oscillator circuit. Harmonic radiation is relatively small, however, because of the high-Q plate-tank circuit employed.

Procedure

The preliminary monitoring survey was conducted over the frequency spectrum, between 150 kilocycles and 25 megacycles, and was carried out at a large number of points within a 1-mile radius of the plant including several in the immediate vicinity. Monitoring was done almost entirely during regular working hours, with equipment operating at normal output, so as to obtain a substantially accurate picture of the radiation problem. This survey not only indicated the characteristics of the existing radiation field, but also allowed the field crew to become familiar with the topography of the surrounding area, and gave them experience in differentiating between radiations from RCA's induction-heating equipment and those from other sources.

Among the methods used to determine the origin of radiations monitored in this survey were (1) the use of directional bearings taken from several points; (2) comparison of signal-repetition rates with the known operating cycles of equipment units in the RCA plant; (3) the characteristic 120-cycle modulation tone of radiations from the self-rectifying oscillators used as power sources for induction-heating equipment. The problem of differentiating between closely spaced induction-heating units operating on the same fundamental frequency also arose. This problem was solved by slightly changing the work coil or the tank-circuit capacitance of one of the units so as to obtain a suitable change in frequency without an appreciable change in power output. This method was also employed in cases where the frequency of the induction-heating unit was the same as that of an authorized service.

The preliminary monitoring survey and all subsequent certification measurements were carried out using a Stoddart Aircraft Radio Co. Radio-Interference and Field-Intensity Meter Model NM20A. This meter is equipped with both loop and rod-type antennas, and is the equivalent of the military type AN/PRM-1 Field-Intensity Meter.

The survey showed that (1) approximately 27 percent of the rf induction-heating equipment in the plant produced no detectable radiation at a distance of one mile, and consequently, would not require modification; (2) approximately 53 percent of the equipment produced radiation of up to 25 microvolts per meter at one mile, and consequently would probably require only slight modification; (3) the remaining 20 percent of the equipment produced radiation of between 25 and 200 microvolts per meter at one mile, and consequently might require considerable modification; (4) no harmonic radiations exceeding the 10-microvolt-per-meter limit at one mile were detectable.

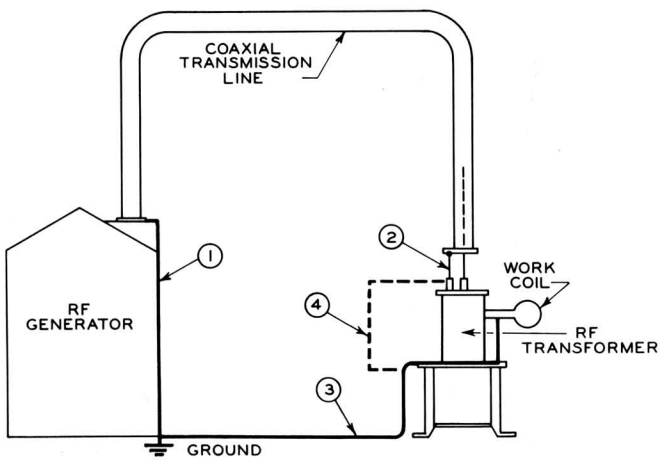
In addition to the experience benefits described above, a number of short cuts were developed during the preliminary survey which considerably simplified and speeded up the final certification measurements. One of the most valuable of these eliminated the time loss normally involved in recalibrating the gain of the field-intensity meter after each change in signal frequency. It was found that when the gain of the instrument was set at an arbitrary value between 30 and 35 db on the lowest frequency band, subsequent field-strength measurements at any frequency would not be in error by more than 6 db. A series of correction factors obtained from the gain-calibration charts furnished with the instrument was then used to convert actual readings to true values. Extensive tests showed that no errors resulted when measurements were made in this manner.

Two effects which had been predicted were noted during the preliminary survey. One was that when a loop antenna was used (as prescribed by the FCC) the height of the loop above ground had no measurable effect on the strength of the received signal. This finding made it possible to maintain the instrument at a fixed height above ground, rather than to make measurements of maximum signal strength at various heights up to 12 feet in each location as specified in the FCC regulations. The other was that the presence of an automobile directly behind and in line with the field-intensity meter with respect to the signal source had no effect on the strength of the received signal. This finding made it unnecessary to lose time unloading and reloading the equipment at each measuring point.

Following the preliminary monitoring survey, steps were taken to determine and correct the causes of excessive radiation. In most cases the causes were determinable by inspection and were found to be "loops" existing in the connections between work circuits and rf generators. In some cases these loops were created by

widely spaced ground and "hot" leads (some of these were as much as six feet apart); in others the loops were formed by multiple ground return paths existing between the work table or machine and the rf generator. In another type of installation excessive radiation was caused by the use of long flexible leads between a movable work coil and the output terminals of the rf generator.

On the basis of these findings the plant management decided to modify all induction-heating installations so that standard 51-ohm coaxial cable would be used wherever practical. In cases where flexible leads to work circuits were required, the installations were redesigned so that such leads were not more than six feet long and were run directly to junction boxes at the end of the coaxial cable. A rigid, copper coaxial cable 3 1/8 inches in diameter was selected on the basis of an anticipated peak rf voltage of 13.3 kilovolts and a maximum temperature rise of 80 degrees Centigrade at a current of 200 amperes. The problem of oxidation which might occur as a result of heating at the higher currents, was overcome by silver-soldering all joints, and the temperature rise was further minimized by the use of gray paint on the outside of the cable. Fig. 1 shows a typical installation incorporating the features employed in the modification program. The cost of labor and material for the most expensive single installation was approximately $500, and the cost of the entire modification program was approximately $30,000. The expense of this undertaking was considered justified, because the large margin of safety provided in the new design permitted substantially greater latitude in the use of the equipment than if the radiations were reduced merely to the extent necessary for compliance with the regulations.



(1) Generator Ground.

(2) Unshielded leads to work circuit not more than six feet in length and closely spaced.

(3) Single Continuous safety ground return from work coil and table to generator ground point.

(4) If the primary rf circuit is grounded separately as shown, the large loop formed by the two return paths may readily become a source of radiation.

Fig. 1 – Typical Induction-Heating Installation Showing Methods Used To Minimize Radiation.

Certification Tests

Because of the large number of installations involved and the manner in which they are distributed, it was decided that separate measurements and certifications for several relatively small groups of equipment would be preferable to a single series of measurements and certification for the entire plant. Preparations for the final certification tests were made during the period when the equipment was undergoing modification. These preparations included the drawing of detail maps showing to scale the buildings and topography of the area within a radius of 1000 feet from the center of each equipment group involved. These maps were divided at 20-degree intervals by radials positioned so that, as far as possible, their points of intersection with the 1000-foot circle would be accessible by automobile. They were prepared to permit rapid determination of the radials having field intensities within 15 db of the maximum, as required by the FCC regulations. Maps having concentric circles at 500-foot radius intervals out to the prescribed 1-mile distance from the center of each equipment group were also prepared. These maps were used principally as aids in locating the exact points at which measurements were to be made. It was also necessary to prepare forms on which to list the data required for certification, and to correct the original inventory of induction-heating equipment, since the conversion to coaxial cable had changed many of the operating frequencies (in some cases by as much as 50 kilocycles).

Because of the number of equipment areas involved, the final certification tests required several days. A problem of communication between the field crew and the plant was solved by having the equipment operators in the plant record the exact time any unit was shut down and turned on again. It was then easily possible to recheck the radiation of any unit which might not have been in operation during an actual test period. During the tests each unit of equipment was operated with the highest possible rf current in its tank circuit. In order to achieve these maximum rf current values it was necessary to operate without loads in the work coils.

In the actual certification tests the field-intensity meter was set up on the tail gate of a station wagon. In accordance with FCC regulations, readings were made first at the intersection of each radial with the 1000-foot circle as a means of determining the lobes having radia-

tion within 15 db of the maximum. At each measurement point the meter was tuned over the frequency band from 150 kc to 15 mc in order to include the 10th harmonic of the unit having the highest fundamental frequency. Although no excessive harmonic radiation had been detected outside the plant during the initial survey this recheck was carried out as a precautionary measure.

Every signal which could possibly be attributed to RCA's induction-heating equipment, or which was of uncertain origin was recorded together with all pertinent data. A typical measurement data sheet is shown in Table I. Most of the signals of doubtful origin were eliminated later as successive measurements made it evident that they were not coming from RCA equipment.

Following completion of the 1000-foot measurements, the procedure was repeated on the 1500-foot circle as a means of checking the results. Measurements were then temporarily suspended to permit calculation of absolute radiation field intensities in microvolts per meter. These calculations involved (1) conversion of recorded meter readings for signal field strength and ambient noise[2] to true values; (2) determination of the square roots of the differences of the squares of the field-strength and ambient-noise values; (3) multiplication of the resultants by the recorded attenuator settings, calibration-chart correction factors, etc. Readings which were not obtained at exactly 1000 or 1500 feet were corrected to those points[3]. Throughout these tests the readings obtained with the loop were checked against measurements made using the more sensitive rod antenna. When these calculations were completed polar plots of the maximum field intensities on each radial were prepared for both the 1000-foot and 1500-foot measurements. A sample of such a polar plot is shown in Fig. 2.

With this information available, measurements were then made using the loop antenna along the radials of maximum field intensity. These measurements were carried out at intervals of 500 feet to the prescribed distance of one mile, or until the signals could no longer be distinguished from the ambient noise. At each of these limits additional measurements were made using the rod antenna (which has a minimum sensitivity of 2 microvolts per meter) in order to confirm the trend of the signal. Fig. 3 shows a typical curve of field intensity vs. distance.

These tests showed that the maximum radiation from the plant at a distance of 1 mile less 150 feet was 7 microvolts per meter, and was at a frequency of 697 kc. The unit responsible was one having an output of about

TABLE I

Sample Field-Strength Measurement Data Sheet

DATE: 12-19-52		INTERFERENCE SOURCE: RCA Lancaster Plant											
F.I. METER: Stoddart NM-20A			SERIAL NO: 24			OBSERVER: T.E.N.							
REFERENCE MAP: Bldg. #2, 1000 Radius Circle													
Time	Location	Distance Corp. Mult.	Freq. In Mc.	Correct Cal. Setting	Actual Cal. Setting	Cal. Mult.	Atten. Mult.	Chart Mult.	Ant. Mult.	Meter Rdg. μV	Ambient Noise μV	Computed $\mu V/M$	Remarks
9:10 AM	Radial 5 1000′ 5	–	.256	42	42	1	1	10	1	6.0	5.4	26	
"	"	–	.597	38	38	1	1	20	1	7.8	7.8	0	
"	"	–	.697	37	37	1	1	20	1	5.4	5.1	35.4	
9:30 AM	Radial 6 870′	.87	.256	42	42	1	1	10	1	8.1	7.5	27.2	
"	"	.87	.597	38	37.5	1.06	1	20	1	7.2	7.0	29.2	
"	"	.87	.697	37	37	1	1	20	1	5.8	5.1	48.2	
10:25 AM	Radial 9 1000′	–	.597	38	38	1	1	20	1	8.1	7.5	61.2	
"	"	–	.697	37	37	1	1	20	1	6.6	5.6	70.0	
11:40 AM	Radial 15 860′	.86	.697	37	37	1	1	20	1	6.5	4.8	75.4	

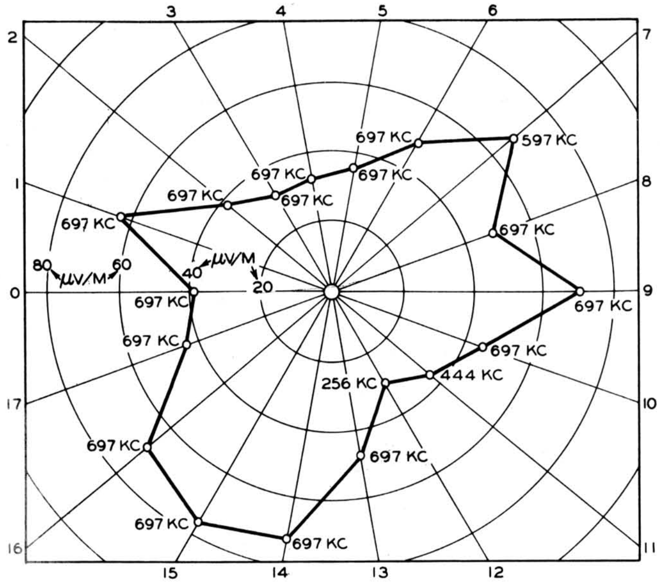


Fig. 2 – Sample polar plot of maximum radiation from induction-heating equipment at 1000 feet.

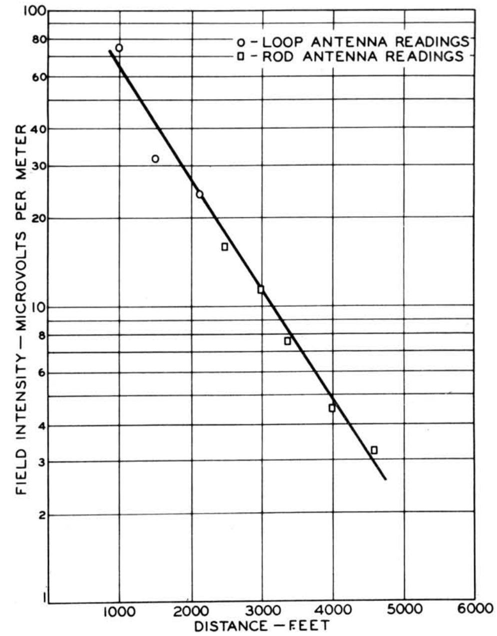


Fig. 3 – Plot of field intensity values (697 Kc) along radial No. 15 in Fig. 3.

3 kilowatts, which was built during the war. Because of the metal shortage existing at that time, this unit was enclosed in plywood and was not shielded in any way. This unit was subsequently rebuilt, and radiation from it cannot now be detected beyond 1000 feet.

FCC regulations also require that a series of radiation measurements be made along a 500-foot length of the power line feeding the induction-heating equipment. This 500-foot length must span the 1-mile point, and three measurements must be made on each of three perpendiculars to the line within this length. The measurement points must be within 50 feet of the line. The certification tests made in accordance within this regulation showed that there was no power-line radiation from the plant.

Upon completion of the certification tests a certificate was prepared for each of the equipment groups checked. This certificate was posted in the area concerned as prescribed by the FCC Regulations. Each such certificate was accompanied by an engineering report listing the equipment covered by the certification, a description of the testing methods used; the pertinent maps, polar curves, and curves of field intensity vs. distance; the original test data; and descriptions and results of all tests made to justify the short cuts previously described. This report was filed in the office of the plant manager, and forms part of the certificate.

Since the completion of these tests a number of induction-heating units have been added at various times, and an individual survey made for each unit. The reports on these units were made appendices to the reports for the original program, so that no changes were required in original certificates of compliance. The design of these newer units has been such that very seldom have we been able to measure the radiation even at 1000 feet. The results in most cases show a maximum radiation of 10 microvolts per meter at 250 to 300 feet from the center of the enclosing circle. These measurements are usually made on the radial which allows closest access, outside of the building, to the unit being measured.

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References

1. Federal Communications Commission Part 18 Rules and Regulations Relating to Industrial, Scientific, and Medical Service. Operation without a license; Industrial heating equipment sections 18.21 thru 18.24.
2. Instruction Book for model NM-20A Radio Interference and F. I. Meter, Stoddart Aircraft Radio Co. Hollywood, California, Section 4e.
3. Terman, F. E., RADIO ENGINEERS HANDBOOK, McGraw-Hill Book Co., New York, N.Y. First edition 1943 – page 681.