

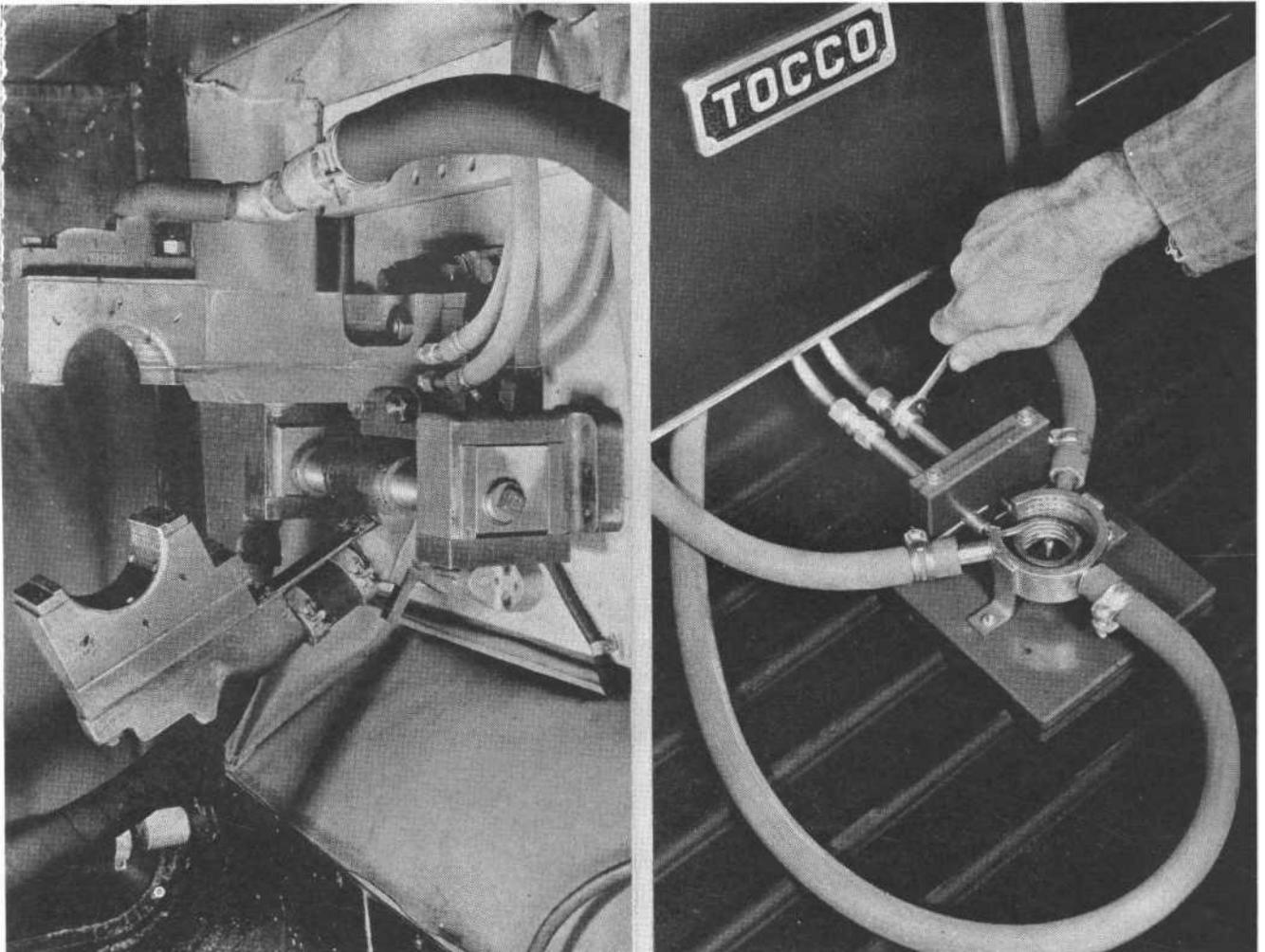
High Speed Heating by Induction

One of the recent outstanding developments in the heat treating field has been the application of induction heating to localized surface hardening. The advances made contingent with the application of high frequency current have been nothing short of phenomenal. Starting a comparatively short time ago as a long-sought-after method of hardening bearing surfaces on crankshafts (several million of these are in use setting all time service records), today finds this very selective surfacing hardening method producing hardened areas on a multiplicity of parts. Yet, in spite of its present day breadth of application, induction hardening is still in its infant stage. Its probable utilization for the heat treating and hardening of metals, heating for forging or brazing, or soldering of similar and dissimilar metals, is unpredictable.

Induction hardening results in the production of locally hardened steel objects with the desired degree of depth and hardness, essential metallurgical structure of core, demarcation zone, and hardened case, with a

practical lack of distortion and no scale formation. It permits equipment design which warrants mechanization of the whole operation to fulfill production line requirements. Time cycles of only a few seconds are maintained by automatic regulation of power and split second heating and quenching intervals indispensable to the creation of facsimile results of exacting special fixations. Induction hardening equipment permits the user to surface harden only the requisite portion of most any steel object and thus maintain the original ductility and strength; to harden articles of intricate design which cannot be feasibly treated in any other way; to eliminate usual expensive pretreatment such as copper plating and carburizing, and costly subsequent straightening and cleaning operations; to cut down on material cost by having a wide selection of steels from which to choose; and to harden a fully-machined item without the necessity of any finishing operations.

To the casual observer it would appear that induction



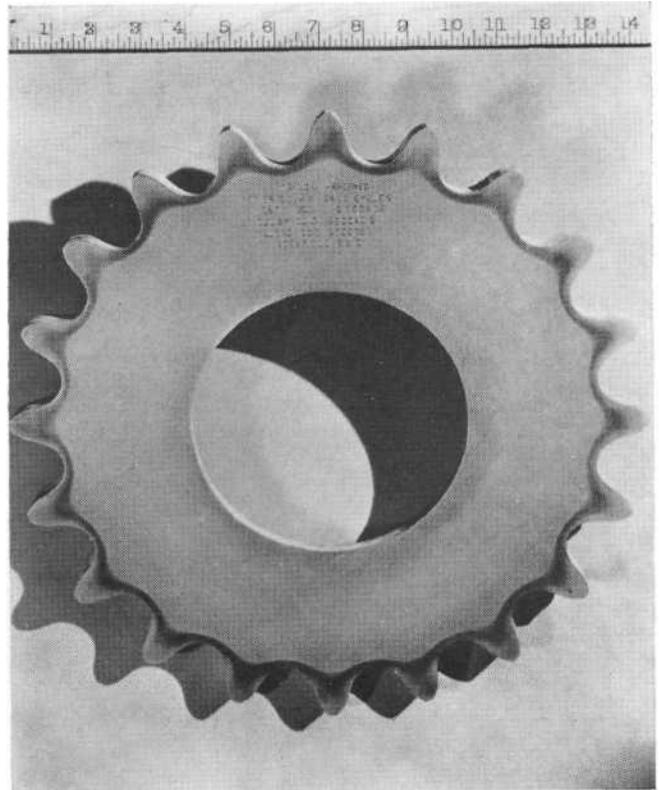
• Typical inductor blocks for heating piece to be hardened. Note orifices for the quenching medium.

hardening is possible as a result of some energy transformation occurring within an inductive region of copper. The copper carries an electrical current of high frequency and, within an interval of a few seconds, the surface of a piece of steel placed within this energized region is heated to its critical range and quenched to optimum hardness. To the manufacturer of equipment for this method of hardening it means the application of the phenomena of hysteresis, eddy currents, and skin effect to the effective production of localized surface hardening.

The heating is accomplished by use of high frequency currents. Specifically chosen frequencies from 2,000 to 10,000 cycles and upwards of 100,000 cycles are being used extensively at the present time. Current of this nature in flowing through an inductor produces a high-frequency magnetic field within the region of the inductor. When a magnetic material such as steel is placed within this field, there is a dissipation of energy in the steel which produces heat. The molecules within the steel attempt to align themselves with the polarity of this field, and with this changing thousands of times per second, an enormous amount of internal molecular friction is developed as a result of the natural tendency for the steel to resist changes. In this manner the electrical energy is transformed, through the medium of friction, into heat.

However, since another inherent characteristic of high frequency current is to concentrate on the surface of its conductor, only the surface layers become heated. This tendency, called "skin effect", is a function of the frequency and, other things being equal, higher frequencies are effective at shallower depths. The frictional action producing the heat is called hysteresis and is obviously dependent upon the magnetic qualities of the steel. Thus, when the temperature has passed the critical point at which the steel becomes non-magnetic, all hysteretic heating ceases.

There is an additional source of heat due to eddy currents which flow in the steel as a result



• Polished and stained sprocket showing selective depth hardening.

of the rapidly changing flux in the field. With resistance of the steel increasing with temperature, the intensity of this action is decreased as the steel becomes heated, and is only a fraction of its "cold" original value when the proper quenching temperature is reached.

When the temperature of an inductively heated steel bar arrives at the critical point, heating due to eddy currents continues at a greatly reduced rate. Since the entire action goes on in the surface layers, only that portion is affected. The original core properties are maintained, the surface hardening being accomplished by quenching when complete carbide solution has been attained in the surface areas. Continued application of power causes an increase in depth of hardness, for as each layer of steel is brought to temperature, the current density shifts to the layer beneath which offers a lower resistance. It is obvious that the selection of the proper frequency, and control of power and heating time will make fulfillment of any desired specifications of surface hardening possible.

Metallurgy of [Induction Heating](#)

The unusual behavior of steel when heated inductively and the results obtained merit a discussion of the metallurgy involved. Carbide solution rates of less than a second, higher hardness than that produced by furnace treatment, and a nodular type of martensite are points of consideration

that classify the metallurgy of induction hardening as “different”. Further, surface decarburization and grain growth do not occur because of the short heating cycle.

Induction heating produces a hardness that is maintained through 80 percent of its depth, and from there on, a gradual decrease through a transition zone to the original hardness of the steel as found in the core which has not been affected. The bond is thus ideal, eliminating any chance of spalling or checking.

Complete carbide solution and homogeneity as evidenced by maximum hardness can be accomplished with a total heating time of 0.6 second. Of this time, only 0.2 to 0.3 second is actually above the lower critical. It is interesting to note that induction hardening equipment is in every day operation on a production basis with complete carbide solution, resulting from a heating and quenching cycle, the total time of which is less than 0.2 second.

The fine nodular and more homogeneous martensite which results from the induction hardening is more readily apparent with carbon steels than with alloy steel because of the nodular appearance of most alloy martensite. This fine structure must have for its origin an austenite which is the result of a more thorough carbide diffusion than is obtained with thermal heating.

Practically instantaneous development of critical temperatures throughout the entire microstructure of the alpha iron and iron carbide is particularly conducive to rapid carbide solution and a distribution of constituents which has as its inevitable product a thoroughly homogeneous austenite. Further, the conversion of this structure to martensite will produce a martensite which possesses similar characteristics and a corresponding resistance to wear or penetrating instruments.

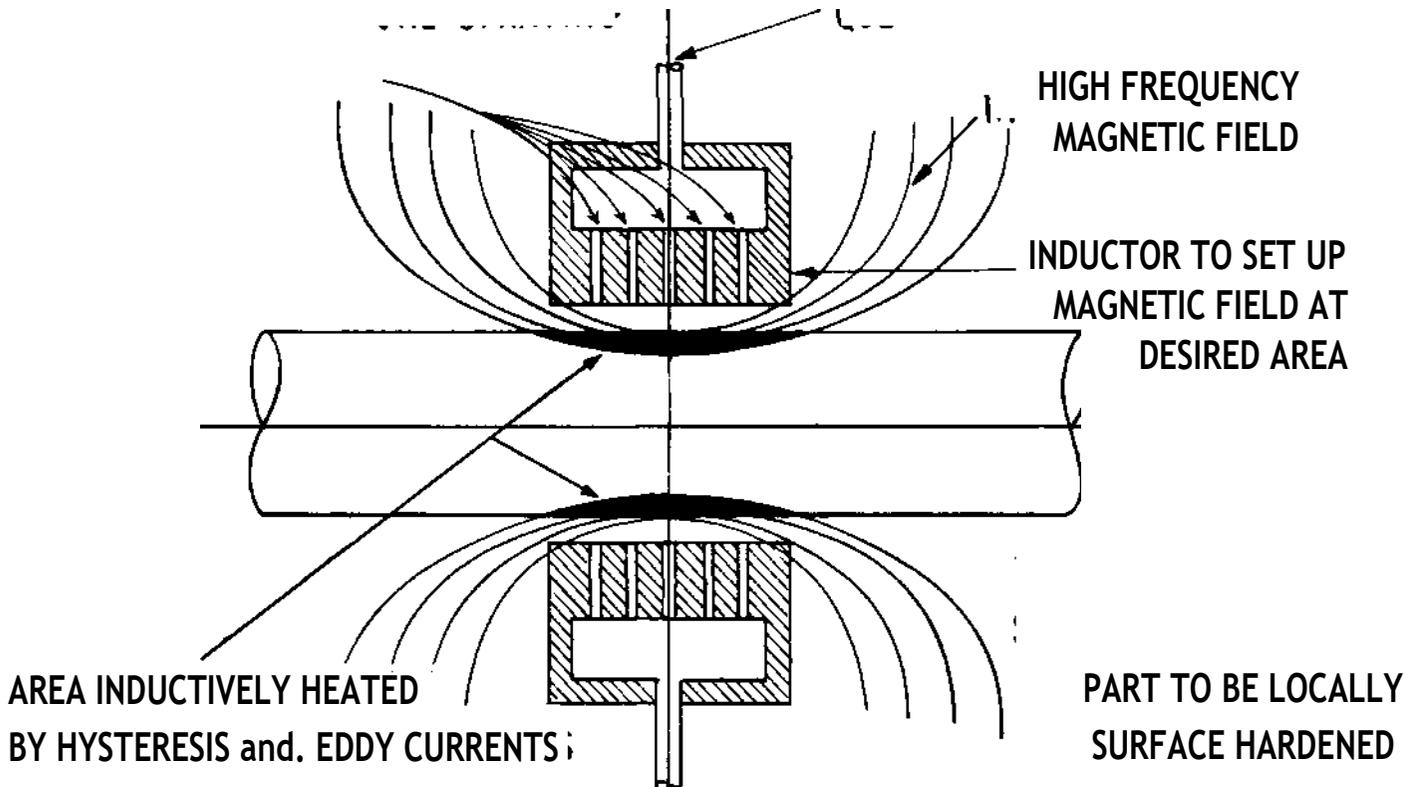
Equipment Used

All surface hardening equipment consists of an inductor, quenching auxiliaries, suitable transformers and capacitors, automatic timing controls, and a high frequency generator. In addition, provisions are made for handling of the parts intermittently or continuously depending upon production requirements.

The inductor may be a single turn of copper to fit the piece to be hardened or several turns of copper tubing shaped for the same purpose. Careful design is essential at this point to insure maximum efficiency. However, symmetrical inductors may be used to surface harden unsymmetrical objects because of the natural tendency of the high frequency current to follow the contour of

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ORIFICES FOR PRESSURE SPRAYING OF HEATED SURFACE



• Schematic diagram of piece being inductively heated. Note limited effective magnetic field.

INDUCTION HEATING (Continued from page 11)

the piece. The quenching medium is supplied through the inductor by means of orifices which are an integral part of it. The same timing device which controls the heating cycle operates an electric quench valve and controls the quenching cycle to the same degree of accuracy.

Large frequency-converters of the motor-generator type are in every-day use for 2,000, 3,000, and 10,000 cycles. Smaller units of the spark-gap oscillator type are used at frequencies upwards of 100,000 cycles. Extremely high frequencies are available from vacuum tube oscillators; but the manufacturers have been slow in developing more economical designs of this type of high frequency generator. Indications are that the increased demand for reliable sources of these higher frequencies will shortly change this situation.

The high frequency current is usually generated at high voltage ranging from 200 to 1,000 volts depending upon the particular unit. It is then transformed to lower voltage of 20 to 50 volts and fed into the inductor. The transformer is designed for the specific frequency and the inductors to be used with it. In some instances, where a multiturn coil is employed, the transformer is eliminated and connection made directly across the generating source.



• Commercial 10,000 cycle induction hardening unit.
—Courtesy Westinghouse

In order to obtain high efficiency, the high frequency

QUENCH MEDIUM INLET

power factor is adjusted and maintained as near unity as possible. This is accomplished by connecting in the circuit the proper amount of capacitance. Variations in capacitor requirements are readily accommodated by a switch mechanism which provides immediate change of the number of condenser units.

The power used for each hardening operation is controlled and maintained by the field excitation of the generator. Occasionally it is found that a fixed excitation will not produce a constant power output due to the electrical characteristics of the steel changing during the rising temperature. A longer, undesirable heating cycle would result. However, the power is maintained constant by an automatic control system which changes the external resistance of the field circuit at pre-set, split second type intervals while the power is on.

It would be impossible at this time to make any definite statement concerning all the steels to which the induction hardening method could, and all those to which it could not be applied. There are certain requirements, however, which are quite obvious. The carbon content must be sufficient to produce the desired hardness although, as has been pointed out, higher hardness is possible with this method of hardening. A fine grain size is preferable yet not always essential. Due to the excessive demands put on crankshafts, it has been found advisable for such and similar parts to use a heat treated structure which is predominantly oolitic or a normalized structure having a grain size comparable to the heat treated. Low carbon steels with carburized case, medium and high carbon steels both regular and alloy, and ordinary cast iron in a malleable pearlitic condition can all be hardened as desired. Generally speaking, any material which will respond to a heating and cooling operation may be hardened or heat treated by induction.

In the automotive field the successful and economical hardening of camshafts is of utmost importance. Costly pretreatment, hardening, straightening and cleaning operations all add up to an expensive production. The application of induction hardening, with its very selective nature, to the surface hardening of camshafts eliminated this by producing a shaft free of distortion and scale and hardened only where necessary. Each camshaft unit, automatically hardens two shafts with one loading operation, and the surface hardness follows the contour of the cam.

Rocker arm shafts for combustion engines are surface hardened in areas on which the rocker arms operate. Distortion is reduced to a minimum and production becomes extremely high. The shaft moves through an inductor and is stopped for each area by an indexing mechanism and is then discharged from the machine. A timing device controls the entire operation and makes it automatic once the shaft is placed in the machine.

In addition to the selective surface hardening of steels there have been other applications of induction heating of rather a unique nature. Hardening a piece of steel and brazing to copper and other metals may be done simultaneously. A small section of a previously hardened object can be drawn or softened to a condition permitting ready machinability. Heating for forging and upsetting has been found to be a particularly satisfactory use for induction heating. The speed with which this may be accomplished has made it readily adaptable to the high production requirements of forming equipment, and scale problems are reduced to a minimum. Tip annealing of brass cartridge shells at the rate of 100,000 per hour is provided with a single induction heating unit. Piston pins may be hardened progressively with surface hardness and core properties as desired at a rate of 2,000 per hour with one machine.

In conclusion, where speed, accuracy and control are important, the consideration of induction heating is most essential. Adoption of induction heating and hardening is justified by the solution of a problem unsolved by other means, a marked advantage in quality, a decrease in overall cost, or sufficiently large production of one or more parts to permit the rapid amortization required by industry.