MANUFACTURE OF TAPE TOROIDAL CORES

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The manufacture of tape toroidal cores at the Kearny Works involves physical characteristics hoping that by meeting these, the electrical performance of the apparatus will then be acceptable. Material is received from the supplier in the form of coil stock weighing approximately fifty pounds each. They are wound on a rotating arbor which is the control of the inside diameter of the core. The material is wound up to an outside diameter which is now judged by eye. As the material approaches the outside diameter the operator of the machine slows down the machine and then stops it when this dimension is reached. (See Fig. I) Material is always overwound on the coil because there is a variation of material thickness, variation of tension of material being wound and a variation as to when the machine will be stopped by the operator. In addition to this, there is a variation in the magnetic properties of the material which can not be detected by these measurements at this stage. The cores are then put on scales and material is stripped off to bring the weight down to a controlled limit. After an annealing process to relieve the stresses of the material is completed, the cores are wound with their various turns of wire and insulating material, impregnated in an epoxy and then become a completed coil winding assembly. They are now tested as a ferro-resonant transformer for output and regulation along with the other necessary tests. At this time it is necessary to either add turns or take turns off in order to achieve the proper output limits and regulation requirements. This we feel is largely due to the variation of the magnetic core material which up to this point was not measured in any way in our processes. Even with using all of these available parameters we have had to junk coils because we could not compensate the coil enough to obtain an acceptable transformer.

It was thought therefore to try to find some parameter of the core which could be measured and also act as a control so that while the core material was being wound we could measure an output, feed this output into a control circuit and possibly stop the machine automatically. With this as an objective we would end up with only good core material and eliminate many costly operations and junked parts.

A study was conducted to observe certain parameters and to find out what effect if any the various manufacturing processes had on these parameters. By learning these things we could either try to control them if they had an

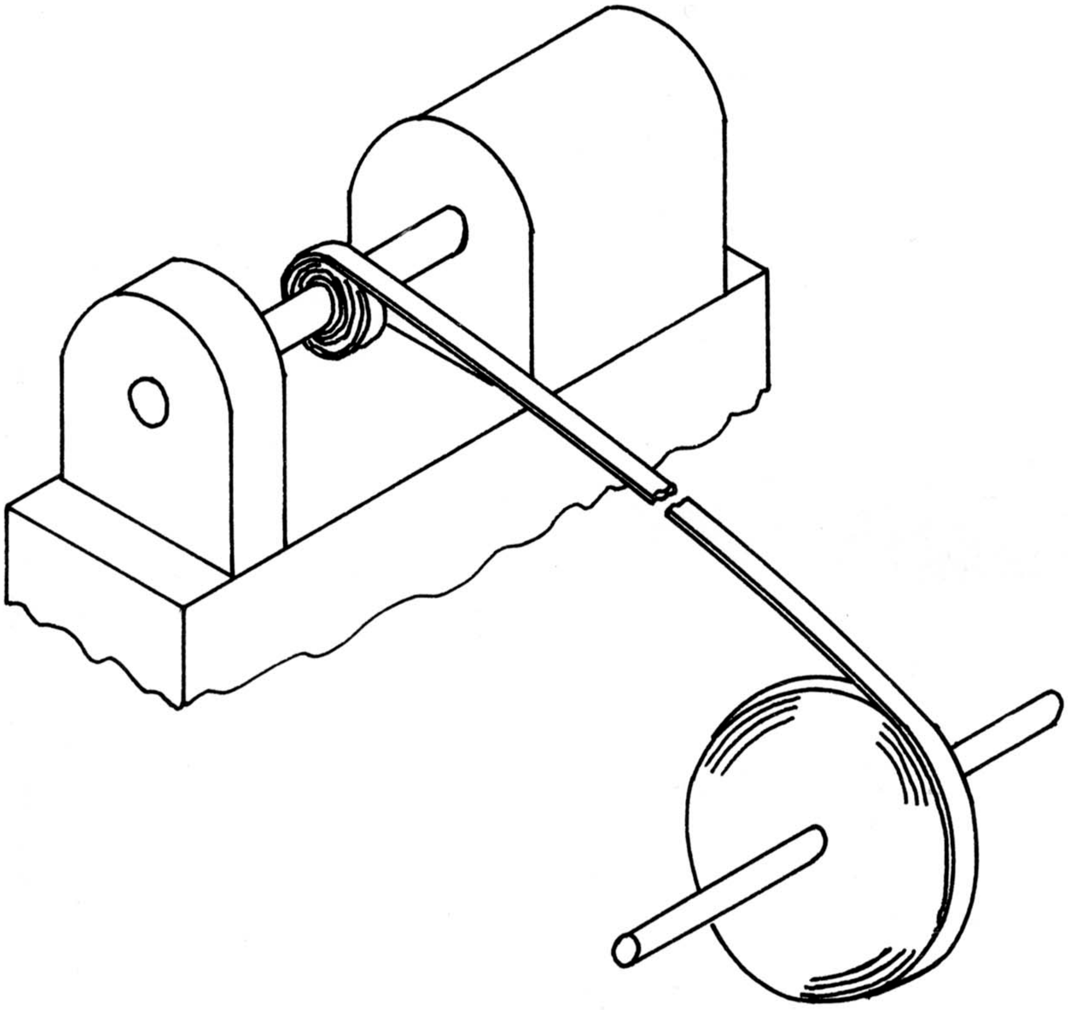


FIG. I

adverse effect or at least take them into consideration while we were making our measurements for control purposes.

At this point I would like to bring out some of the theoretical background and reasoning that led us to the steps that will be explained later. If we are given a particular grade of magnetic material and if we wind this material into a specific configuration, such as a toroid, and then we put turns of wire around this core, we have the necessary basic elements for an electrical magnetic circuit. If a current is caused to flow in the turns of wire around the coil, a magnetizing force is set up depending on number of turns of wire, amount of current and the length of the magnetic path considered. In the case of the toroid we have

$$H = \frac{.4\pi N I_p}{l_c}$$

where N = turns
I_p = peak current or exciting current
l_c = path in core

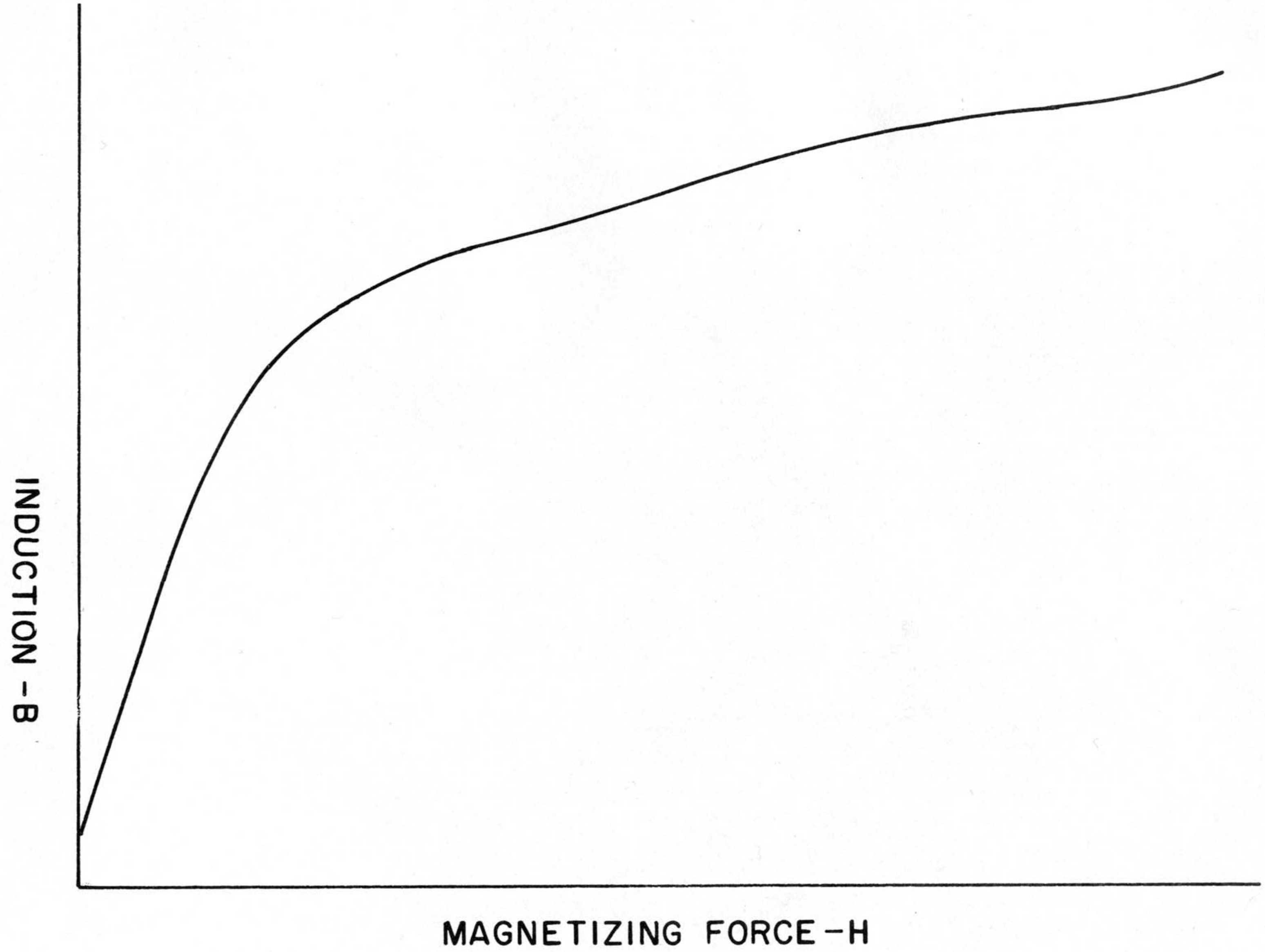
Now this magnetizing force H creates a flux density B. (See Fig. II) This flux density by cutting across a conductor then induces a voltage into that conductor. The value of this voltage is given by

$$Erms = 4.44\ Bmax.\ fNAX10^{-8}$$

where Bmax. = maximum value of AC flux density
f = frequency of flux
N = number of turns of wire around core
A = cross sectional area of core

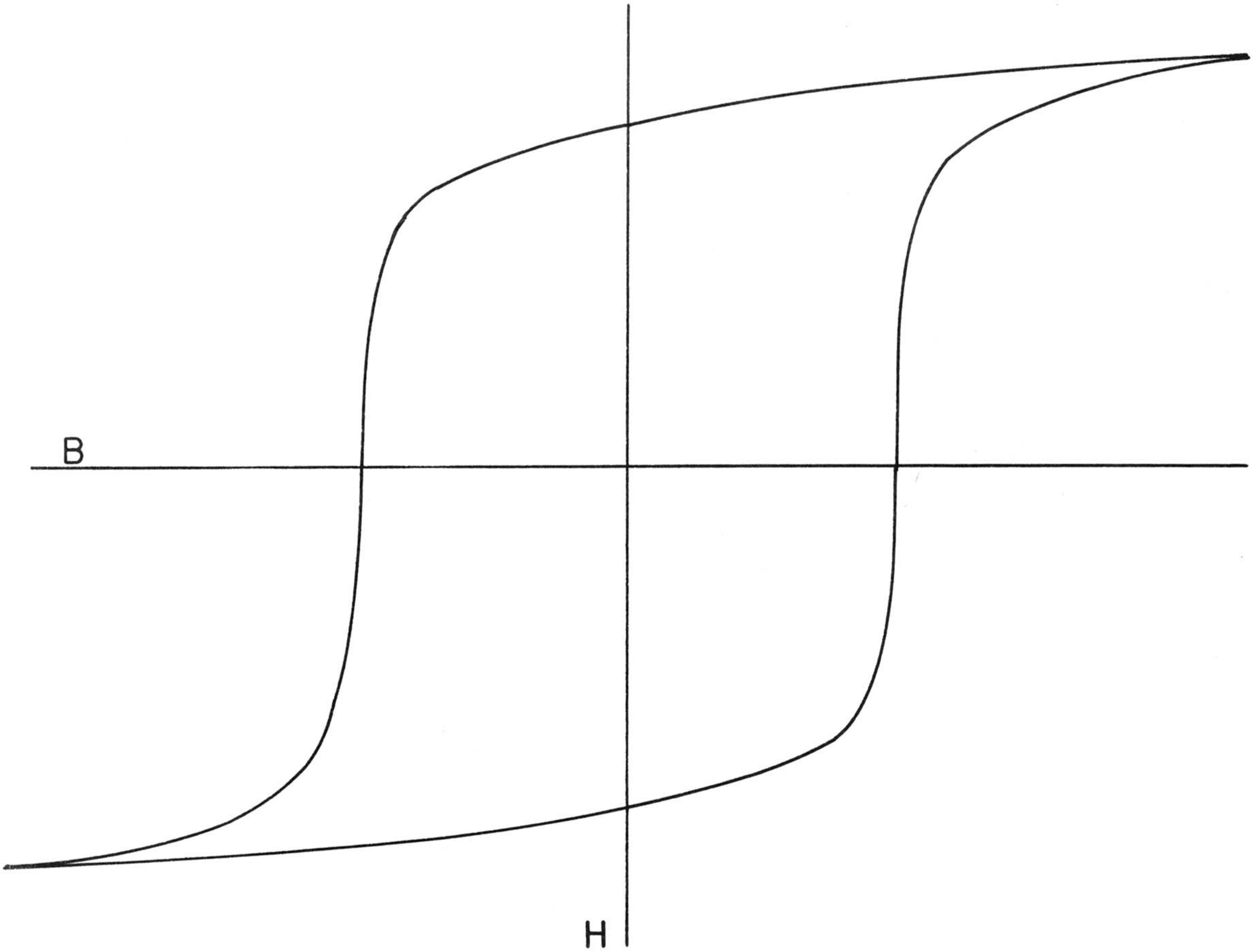
The ease at which a substance can becomes magnetized is known as permeability and may be calculated by B/H.

In this type of circuit there are various losses which must be taken into consideration. When any current flows through a resistor there will be a loss known as copper loss. Since the winding of wire has a finite resistance, this loss will be equal to the square of the current times the resistance of the winding. Another loss will be called eddy current losses. These are caused by currents induced within the core by the varying magnetic flux and flow at right angles to the flux. They are proportional to the square of the frequency, the square of the AC flux density, thickness of lamination and inversely to the resistivity of the core material. The next loss is called the hysteresis loss. (See Fig. III) This is caused by alternately magnetizing the core of the transformer between two limits and is proportional only to frequency for fixed values of flux density. This loss can be calculated by the area enclosed by the hysteresis loop. Since the larger the area the larger the losses. Now the current necessary to take care of all these losses is part of the exciting current. Actually the exciting current is a non-sinusoidal current made up of two parts. The first is the current which is in phase with the induced voltage and is that current to overcome the core losses just described. The second part is a



TYPICAL B-H CURVE

FIG. II



TYPICAL HYSTERESIS LOOP

FIG. III

current that lags the induced voltage by 90° due to the inductive nature of the circuit. This part of the current is known as the magnetizing current and it is this current which establishes the flux density.

Now getting back to the study that was conducted, we found that when there was a low exciting current, the transformer would regulate better than if there were a high exciting current. In light of the above theory, we might say that when a higher exciting current was noted that much of this current was used to overcome core losses and therefore the regulation was poorer because of these core losses.

It was also observed that after an impregnation of epoxy the exciting current would go up and in some instances as much as 250%. A further study in this area seems to be advisable to determine causes and possible ways to prevent them. It is possible that stresses are set up in the material from this operation which would cause a change in the hysteresis loop area and thereby causing greater hysteresis losses. If this were true then more current would be used for these losses. It was also noted that the lighter the core was, the more pronounced the effect of the epoxy impregnation and greater percentage increase of exciting current.

The effect of strain was shown by measuring exciting current and plotting the hysteresis loop of cores before and after annealing. The exciting current was between five and six times higher before annealing than after annealing. This is due to upsetting the grain orientation pattern of the material. This particular factor of stresses will prove later to be one of the most troublesome.

Now if we knew what the hysteresis loop will look like as we are winding our core, it would theoretically follow that by applying a fixed exciting current to induce an increasing voltage due to the increasing cross sectional area of the core being wound and increased flux density incurred since

$$E = 4.44\ \text{Bmax.}\ fNAX10^{-8}$$

we could wind good cores.

This voltage limit would be one control and would presuppose good core material. Another control would have a micro switch trip when the core reaches some maximum size limit. Both of these signals could then be fed to a control circuitry either of which would cut the material from the reel, stop the winding of the machine and perhaps seal off the end of the winding by spot welding. In the case where the size limitation was met first, a circuit could easily be designed to indicate that for some reason this core would not be acceptable and the material taken away before more unacceptable cores were wound. Another possible approach to the same objective might be to alternately apply two different current values. This could be accomplished by employing a flip-flop circuit as the input. By knowing that as we approach saturation of the B/H curve our difference in voltage outputs will become some fixed value. By taking this difference in voltage output we could use it to activate our associated controls and complete operations as described before.

It would seem from the above discussion that our problem is solved and everything is operating very smoothly, but there is a minor difficulty which hasn't quite been settled yet. As we mentioned before, whenever magnetic materials are subjected to stresses, the magnetic properties of the material is changed and there are losses in the circuit because of it. This can be seen by observing the hysteresis loop of material with stresses and compared to the hysteresis loop of material without stresses. Since we are winding a fairly tight core on our arbor, it is necessary to tension the material being wound. This tension introduces stresses into the material which vary considerably.

We will probably take steps to control the tension in the winding and see if the variation in the material can be brought to some small deviation. If this is possible we may be able to meet our objective by the above approaches.

As you have read, this paper does not give any final solution to the problem but only a possible approach which is currently under investigation.

Information on other endeavors along these lines would be appreciated by the author.

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