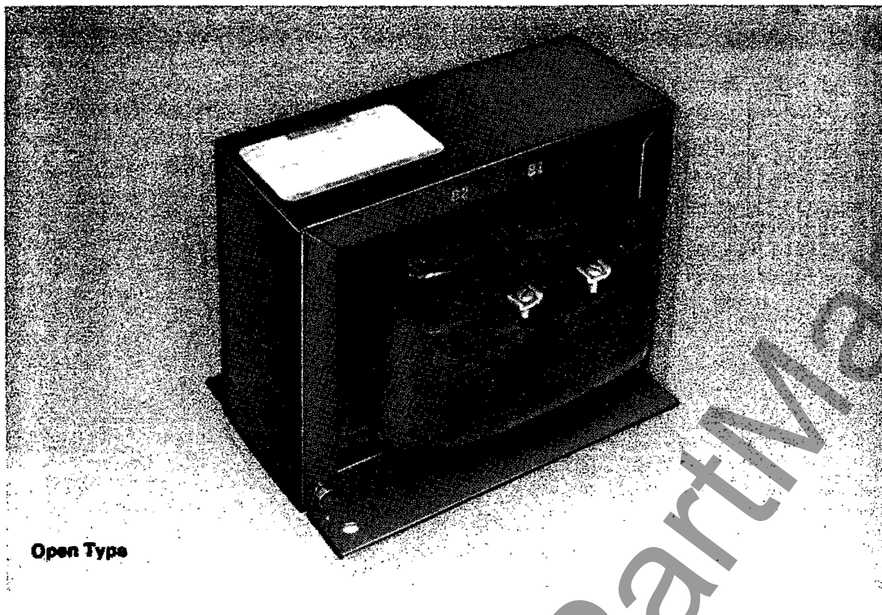
Westinghouse

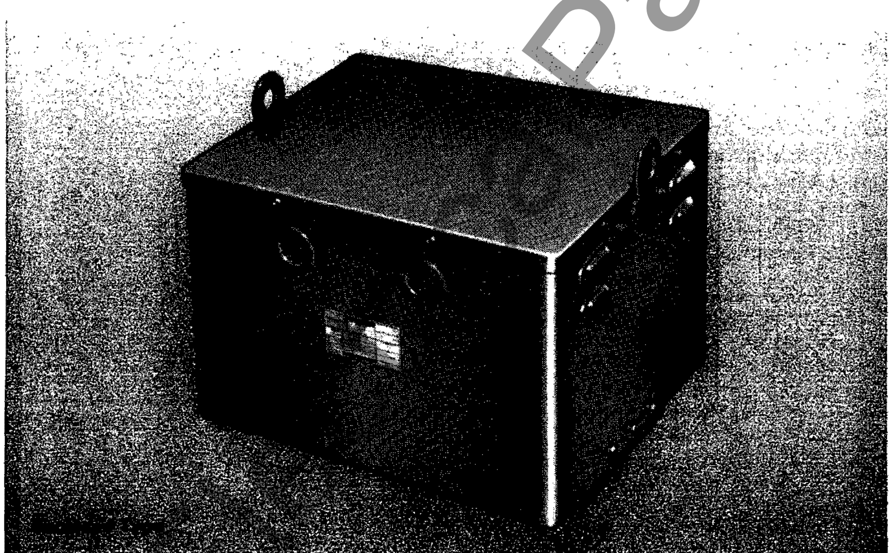
Saturable Core Inductors

Type SCI, Group II Insulation

Air Insulated, 60 Cycles, 80 C Rise
Single and Three Phase
600 Volts and Below



Open Type



Application

A saturable core inductor is a variable impedance device. Its performance may be likened to a variable resistance in a d-c circuit, except that its impedance is changed by controlling the magnetic saturation in an iron core by circulating a direct current. With no d-c excitation, it behaves as a simple iron core inductor. With 100% d-c control current applied, the core becomes saturated with d-c flux, thereby reducing the inductor's impedance as far as a-c is concerned. Thus a complete range of control from 1% to 100% power can be obtained in a smooth stepless manner. Large amounts of a-c power can be controlled by a small amount of d-c power, usually 1% or less of the a-c power to be controlled. Some applications are listed below:

1. To control the current in a load of approximately constant resistance.
2. To maintain a constant current in a load of variable impedance.
3. As a variable loading reactor to provide the lagging component in testing of alternating current generators.
4. To control motor starting voltage when allowable increments of motor starting current are small, and when starting current must be closely controlled.
5. For speed control of motors, either direct on a-c motors or through rectifiers to control armature current in d-c motors.

Advantages

Since saturable core inductors are a static device, and contain no moving parts, they present no maintenance or spare parts difficulties, as would appear in an induction regulator or powerstat. They do not necessitate shutting down the circuit to make voltage adjustments as in a tap changing transformer. Since without d-c control current, impedance is high, they are inherently a "fail safe" device. Manual or automatic control can be located at any convenient control point, some distance from the inductor itself.

Special performance, other than that covered herein, may require a change in the kva rating of the parts used or a special core-coil configuration. The term "kva rating of load" means the kva of load which the saturable inductor is capable of controlling.

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New Information
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Design Characteristics

To fully describe possible misapplications, it is necessary to examine each characteristic and its effect upon inductor performance.

A-c Line Voltage

The maximum no-load flux density is determined by the line voltage. Commercial practice provides a minimum of 10 percent voltage and a maximum of 90 to 95 percent voltage into a unity power factor load. If the a-c line voltage is greater than that for which the inductor was designed, the core will tend to saturate with a-c flux, and the reactance will thereby decrease. Under these circumstances, the d-c control tends to become ineffective and the minimum voltage to the load will be larger than the normal 10 percent minimum. If the a-c line voltage is greatly above the design value, the core will become saturated completely with a-c flux, and the device will act as an air-core reactor. Under such a condition, the d-c control will have no effect whatever. It is possible that the a-c current may rise to such a magnitude as to burn out the a-c coil.

If the line voltage value is lower than the design value, more than the original design value of d-c control current will be required to achieve the 90 to 95 percent maximum output. In application, this means that either the thermal rating of the d-c coil will be exceeded with a resultant failure, or the operating range of a-c control will be limited to substantially less than the guaranteed value. In practice, reasonable performance can be anticipated if the actual line voltage is within plus or minus five percent of the design voltage.

Frequency

As with a transformer, flux density is determined by the frequency of the supply. A frequency lower than normal will cause saturation of the core at no load by the a-c flux, thus rendering the control ineffective. A frequency higher than normal will decrease the no load flux density and thereby require more than the design d-c current to produce the guaranteed 90 to 95 percent maximum of line voltage at the load.

Phase

On three-phase systems, general practice is to connect the inductor in series with the line. The inductor a-c design voltage must be equal to line to neutral voltage, whether the load is delta or wye connected. In such a connection, two of the three inductors share line-to-line voltage at all times. Since these voltages add vectorially, each inductor effectively sees line voltage divided by 1.732. Misapplications of saturable inductors often result from failure to observe this factor on three-phase systems. The result is that the operating voltage of the inductor will be lower than the value for which it is designed, and full output cannot be achieved.

A-c Load

Commercial practices guarantee load current control from a minimum 10 percent to maximum 100 percent for a given design. Along with the voltage guarantees of 10 percent minimum to 95 percent maximum, this provides control power from 1 to 100 percent. In this case, power is defined as the product of current and load voltage.

Saturable core inductors are intended to work into a constant impedance load of the magnitude for which they are designed. If a given inductor is used on a load lower or smaller than that for which it is designed, the control characteristics will change. For example:

A 15-kva inductor is applied to control a 10-kva load. The minimum load current will be determined by the exciting current of the inductor. The minimum current, in this case, would be equal to the exciting current of the 15-kva inductor and would be greater than the exciting current of a 10-kva inductor.

To obtain the maximum voltage and current, the required control power would be considerably less than that normally required for the 15-kva inductor controlling a 15-kva load.

A small degree of overload is permissible. The extent, however, is limited by the thermal rating of the a-c and d-c windings, and the availability of the d-c control power. To obtain an over-rated a-c current, it is necessary to drive the control winding harder than the design level. The increase in d-c control current is greater in proportion than the increase in a-c current.

For example, a 10 percent overload in a-c current can require approximately 20 to 30 percent more than rated d-c control current. If the control power source does not have this capability, the overload cannot be achieved. Due to this nonlinear relationship between a-c and d-c current requirements there is a very definite limit to the amount of overload that can be obtained. Consequently, the physical size of an inductor built for a short-time duty cycle does not diminish in the same ratio as would a transformer.

For a variable impedance load, the design mus be based upon a-c line volts and maximum load current. A constant power load, for instance, whose resistance might double during operation, will require a saturable core inductor twice the kva size indicated by the power rating of the load.

Power Factor

As previously stated, saturable core inductors are rated on the basis of the unity power factor load that they control. For a lagging power factor load, such as an induction motor, the inductor voltage adds arithmetically to the reactive voltage component of the load. For a given condition, the same degree of control cannot be obtained with a lagging power factor load as with the unity power factor load. To obtain 95 percent of the line voltage across the lagging power factor load, the voltage across the inductor must be substantially less than 31 percent of line voltage drop shown on page 4, figure 2. This requires more d-c control power. In terms of physical size, the inductor will be considerably larger.

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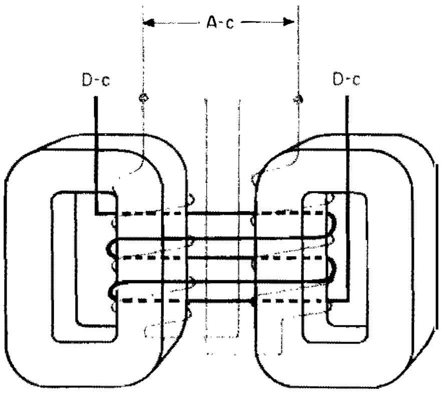
Construction



Simple Two Loop Core Design

The inductor consists of a pair of a-c coils placed on separate cores as illustrated above. A single direct current control coil surrounds these two a-c coils. The a-c coils are connected to each other in such a manner as to establish flux traveling in opposite direction in the two core loops which results in the control coil having a net result of zero voltage induced in it. Thus, there are no disturbances created in the control circuit. The control coil can then be used to establish d-c flux in both core loops and the desired degree of flux saturation.

The normal and most desirable arrangement is to connect the a-c coils in parallel. This forces the voltage across both a-c coils to be equal and effectively prevents any alternating voltage from being induced in the d-c control coil. If the a-c coils are connected in series, equal voltages do not occur in each coil because of the inherent differences in core excitation. The unequal fluxes in the cores result in voltage being induced in the control coil. For low impedance d-c supplies, this may be no problem. With this type of construction, the entire core is active and carries both d-c and a-c flux. The extremely low hysteresis loss in Hipersil cores is particularly valuable in saturable core inductors because the core loss comes primarily from the displaced hysteresis loop.

Operation

The most unusual characteristic of the saturable core inductor is that the iron core carries both a-c and d-c fluxes at the same time. As the direct current is increased, the d-c flux begins to saturate the core causing the reactance of the a-c circuit to decrease. Conversely, decreasing the direct current increases the a-c reactance until the point is reached where the direct current is zero and the device behaves simply as an a-c reactor. The characteristics of this type of inductor are shown below.

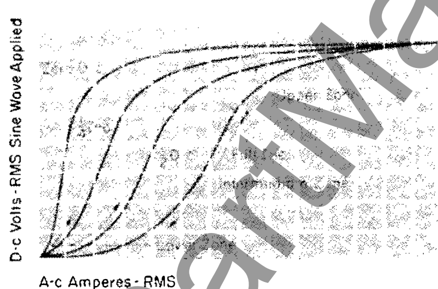


Figure 1: A-c Saturation Curves

The vector diagram shown indicates the voltage relationship of the inductor and the load in a typical constant impedance circuit.

Figure 2 shows the inductor with no control current applied. Here, nearly 99% of the applied voltage E_O is developed across the inductor leaving 10% voltage at the load E_L.

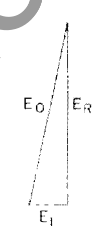


Figure 2

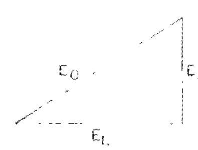


Figure 3

In figure 3, only 31% of applied voltage E_O is developed across the inductor due to the saturation of the core with d-c flux. This leaves approximately 95% of the applied voltage at the load E_L. In larger size units above 250 kva, as little as 15% of the applied voltage is developed across the inductor, thereby leaving 99% of the applied voltage at the load (see figure 4).

The above mentioned values are based on performance with a sinusoidal wave form applied. Results in actual application may vary, since it is nearly impossible to determine the performance with a distorted wave form applied.

In a usual application, the inductor is in series with a constant load impedance which is of the same general order of magnitude as the reactor impedance when fully saturated. By decreasing the d-c control current, the inductor impedance can be varied by a ratio of approximately 20:1.

By examining the vector diagrams, it can be seen that saturable core inductors introduce a lagging power factor condition into the circuit. At full load condition, this will be of a minor nature (approximately .95 pf). At decreasing values of d-c control current, the angle of lag becomes greater, but, since the load current becomes smaller, the effect of the poorer power factor is less important in the system.

Due to the inherent characteristics of an inductive circuit to oppose any change in circuit conditions, there is a definite time lag between the change in d-c control current and the change in a-c impedance of the inductor. This is primarily due to the delay in build-up and decay of the d-c magnetic field. This time lag can be decreased by the following methods:

1. Connecting the a-c line coils as well as the d-c control coils in series.
2. "Forcing" of the d-c circuit by applying over-voltage during the time of change.
3. By keeping the ratio of d-c turns to d-c resistance at a low value and by inserting additional external d-c resistances in the control circuit.

Generally, the standard configuration with a-c and d-c coils connected in parallel provides a time constant suitable for most applications. Special applications such as in motor control or precipitation control require faster response. Inherently faster response requires special inductor and control circuit design to include larger amounts of control power and protection of the control circuit against high induced second harmonic a-c voltages in the control circuit.

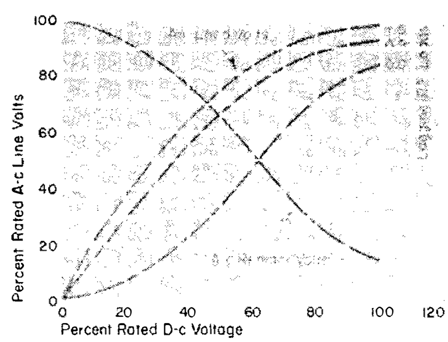


Figure 4: Load Curve Using Saturable Core Inductor Control

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Selection Factors

The saturable core inductor can generally be used in any a-c circuit in which a variable impedance is desired. Factors limiting its use are principally economic. First of all, a variable d-c excitation source must be provided for control. This requires expense additional to the cost of the inductor itself. Second, the cost of saturable core inductors is usually unfavorable as compared to other means of control when power in excess of 2500 kva is to be controlled.

Selecting and applying SCR inductors requires a thorough knowledge of the circuit to be controlled, since the inductor becomes an integral part of the system it is controlling.

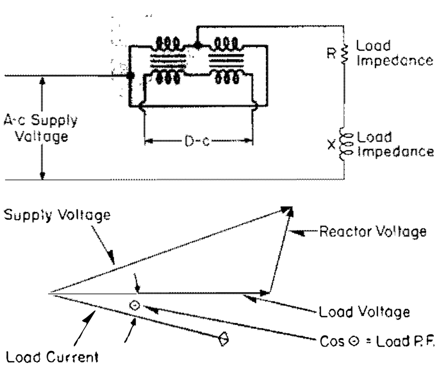


Figure 5: Vector Diagram of Inductor in Series for Varying Current

From the vector diagram (Figure 5) it can be seen that the power factor of the load should be as near unity (100%) as possible to provide proper performance. If the load has a power factor less than 100%, it is apparent that the load voltage with a given inductor will decrease as the power factor angle increases. This can be compensated by overdesign of the reactor, but is generally not practical or economic. In any case, competent design engineers should be consulted on applications where the power factor of the system is something less than 100%. As an example, a inductor designed to control an 85% power factor load over the same range of control as a similar unit for 100% power factor load, can be as much as twice the physical size and cost of the 100% power factor unit. Extreme caution should be exercised in trying to compensate low power factor conditions with capacitors, as resonant circuits could be set up so as to cause difficulty.

Saturable core inductors used on a 3 phase system should be rated at line voltage divided by 1.732. This is due to the fact that inductors are normally placed in series with the line, and share the voltage as though the load were wye connected. This is true even though the load may be connected in delta. Inductors can be inserted in the legs of a delta system, but this is usually less convenient than a series line connection. If a 240 volt rated inductor were placed in a 3-phase system of 240 volts, the a-c voltage impressed across the inductor would be only 139 volts and full control could never be obtained.

Three phase assemblies are generally made up of 3 individual single phase units mounted on a common frame within a common enclosure.

Another application which may be illustrated by the same circuit diagram is a situation in which a saturable core inductor is connected in series with the load for the purpose of maintaining a constant current through a load of variable impedance. This application generally requires a relatively large inductor because the inductor has to be of sufficient size to absorb nearly full-line voltage and, at the same time, carry full-load current. Another useful application of the saturable core inductor is loading a circuit by means of shunt connection. One such application is to supply the quadrature component of a load for testing alternators. In this service, the inductor is called upon to carry full-load current at full-load voltage. The circuit arrangement is shown below:

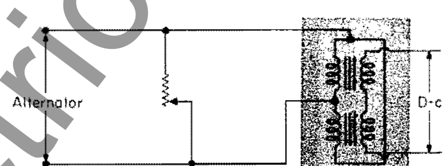


Figure 6: Circuit Arrangement for Testing Alternators

Normal D-c Excitation Requirements

Standard d-c control voltages are 26, 80 and 125 volts.

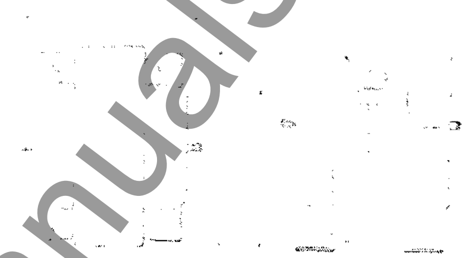
The values shown at right are for normal duty requirements and will produce a minimum of 95% of applied voltage at the load.

In 3 phase applications a-c coils may be arranged for either series or parallel operation from a common source.

Kva	D-c Watts	Kva	D-c Watts
¼	15	2	45
½	17	3	50
¾	32	5	50
1	40	7½	60
1½	40	10	75
		15	85

Weights and Dimensions

Open Type SCI



Kva Rating of Load	Dimensions in Inches A Max.	B Max.	C Max.	Approx. Wt: Lbs.
¼	5	5⅝	5 7/16	9
½	5½	6 7/16	6⅜	14
¾	5 13/16	7½	7¼	22
1	6⅝	8 3/16	8	32½
1½	6 15/16	9 5/16	8¼	35½
2	7¼	10⅜	8¼	44½
3	8	10⅝	8⅞	65
5	9¾	13 3/16	9	95
7½	11¼	15	10	137
10	11¾	15¼	11	160
15	13	15¾	11¼	200

Enclosed Type SCI

Kva Rating of Load	Dimensions in Inches A Max.	B Max.	C Max.	Approx. Wt: Lbs.
3	8 3/16	10 15/16	10 15/16	75
5	9 15/16	13⅛	11⅞	105
7½	11 5/16	14¾	12⅜	150
10	11 13/16	14⅞	12⅜	175
15	13 1/16	16	13⅞	225

Further Information

Prices: Price List 46-830, Page 9.