CHAPTER 1

Introduction to Magnetic Amplifier

The magnetic amplifier, like its familiar electron-tube or semi-conductor counterpart, is a device which reproduces an applied input signal at an increased amplitude, intensity, or power, without appreciably altering the signal's quality or form. Although all types of amplifiers have this common function, the method by which they accomplish the action are vastly different. In the tube amplifier, small voltage variations between grid and cathode (input) control the number of electrons flowing from the cathode to the plate, and relatively large changes in plate voltage (output) are produced. A large degree of amplification, i.e., ratio between output voltage and input voltage, can be realized in the electron tube device, In the semiconductor (transistor) amplifier, application of signal between the emitter and base (input) of the transistor produces large changes in resistivity between collector and base (output), thereby controlling the output current. Because the electrons are injected into the semiconductor through a low input impedance and are collected through a high output impedance, amplification is produced in this unit.

In the magnetic amplifier, the flux variations in a core generated by a signal-derive current (input) flowing through a control winding on the core have a great effect on the impedance of a load winding (output) wound on the same core. In the simplest magnetic-amplifier device, the load winding, connected in series with the load and an a-c source, has maximum impedance when no control current is flowing. At this time, load power is at its minimum. When current flows in the control winding, the impedance of the load winding decreases, and greater power output is delivered to the load from the source. The wide range of fluctuation of load impedance caused by the signal applied to the control winding, and the ratio between output and input powers, produce the desired controllable high gain in the magnetic amplifier device.

In its present state of development, and in view of its large number of applications, the magnetic amplifier has many advantages over other types of amplifying devices. It is a unit having extreme reliability, a long life, ruggedness, no warm-up time, high efficiency, a minimum of maintenance problems, and capable of high-temperature operation.

Fundamentals of Operation.

Basically, the magnetic amplifier is derived from the saturable reactor (or saturable core reactor), which consists of two windings placed on a core. The ferro magnetic core selected for this application has highly rectangular magnetization (B - H) curve. One of the windings, the load winding, is connected in series with an a-c supply voltage and a load, while the other winding, the control winding, is fed by a control voltage, as shown in Fig I. The amplitude of current flowing in the control winding determines the degree of core magnetic saturation, which in turn controls the permeability of the core (ratio between the magnetizing force and the magnetic flux strength).

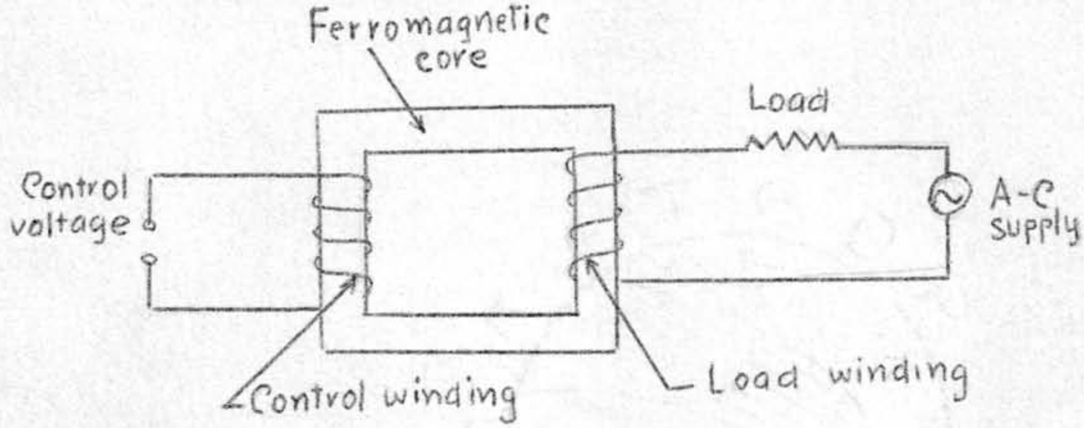

Fig 1. Basic saturable-reactor circuit from which magnetic amplifier is derived.

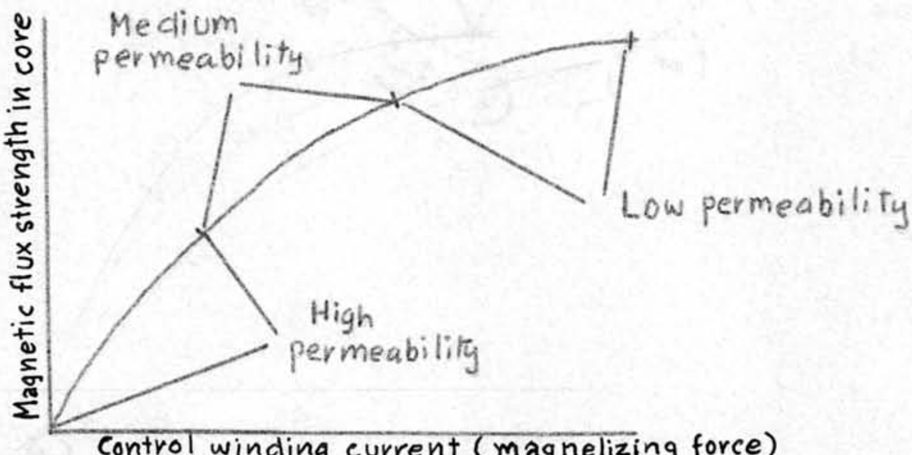

Fig 2. Relationship between control current and magnetic flux in core.

This can be seen in Fig 2. The inductance of the coil and inductive reactance are proportional to the core permeability. Thus the impedance offered by the load winding to the a-c supply voltage, and the voltage appearing across the load, are both affected by the control current. For example, if the control winding drives the core in to magnetic saturation, the permeability is low, the load winding impedance is low, the portion of a-c supply voltage appearing across the load winding is low, and the voltage appearing across the load itself is high. In effect, the fundamental reactor of Fig 1. acts as a switch between the load and the a-c power source, releasing power to the load upon command from the control circuit. Amplification occurs because small changes in control current or power can vary the state of the iron considerably, thereby controlling relatively large powers.

This basic circuit operates without feedback. However, the introduction of regenerative feedback to the circuit can increase the usable gain obtained from the magnetic amplifier by an exceedingly large factor. Bias, too, as in a tube amplifier, can be added to the circuit to select a given point of operation, and thus increases the amplifier's utility.

Control Characteristics of Magnetic Amplifier.

An amplifier is generally used in control applications to increase the power level of a control signal to that value required for operation of an associated load. It acts as the link between the data or control signal and the driven element of the system.

Prior to the development and utilization of the magnetic amplifier, and particularly in case of large power requirements, the thyratron and the amplidyne were used when power amplification was needed to obtain the large power outputs,

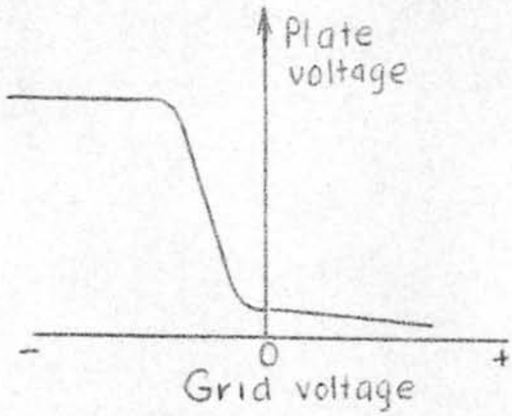

Fig 3. Control Characteristic of a thyratron.

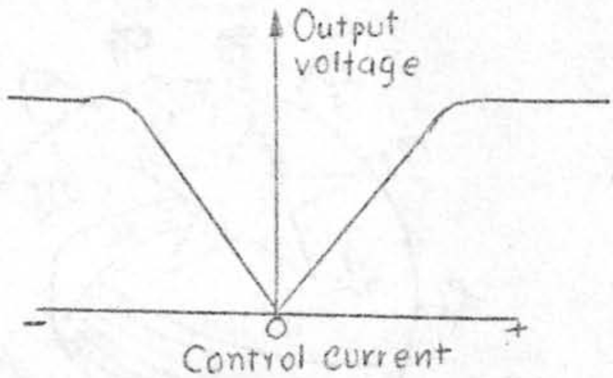

Fig 4. Control Characteristic of an amplidyne.

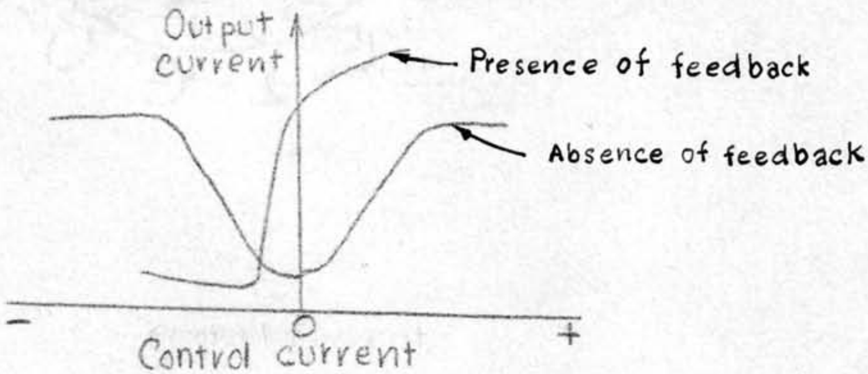

Fig 5. Control characteristic of a magnetic amplifier.

the control characteristic of a magnetic amplifier differs radically between non-feedback and feedback states, as illustrated in Fig 5. In both cases, however, the amplifier can be controlled by either alternating or direct current, and will provide either an alternating or direct-current output.

Applications of Magnetic Amplifier.

Magnetic amplifiers are used in equipment where their desirable characteristics add to the performance, miniaturization, and reliability of the over-all system. The application potential of magnetic amplifiers is set primarily by their unique features. The load action of a magnetic amplifier is similar to that of a synchronous switch which stays closed for a control portion of the cycle of line voltage. This is the key to the uniqueness of the magnetic amplifier, and from it a number of conclusions can be drawn.

1. Like the synchronous switch, the magnetic amplifier will be alternately conducting and nonconducting once during each cycle of line voltage. In its nonconducting state it dissipates no power in its load windings. When it conducts, though, the power lost is the I^2R due to load current and winding resistance. This suggests that the efficiency can be kept high by suitable design. It contrasts with the inherent power loss in the plate and collector circuits of class A or B vacuum tubes or transistors, and it compares favorably with the high efficiency of thyratron.

2. Like the thyratron, the magnetic amplifier draws power directly from the a-c line and does not require the plate supplies necessary in vacuum-tube circuits.

3. The magnetic amplifier has no filament and does not require either the warmup time or the filament-voltage regulation necessary with vacuum-tubes and thyratrons.

4. The magnetic elements of the magnetic amplifier are very rugged and, if properly manufactured and cased, have operating lives measured in decades. It has been difficult to design these features into vacuum-tubes or thyratrons.

These characteristics of the magnetic amplifier have special importance when substantial amounts of power must be controlled. For example, the design possibilities for an amplifier with a power output of 150 mw are quite broad, because all three methods vacuum-tube, transistor or magnetic amplifier-could be used with equal success. At these low-power levels high-circuit efficiency is not so important, because power of a few hundred milliwatts does not ordinarily raise the temperature of a component to a level where its life is reduced. The choice of premium tubes or transistors permits equipment performance for many thousands of hours. This span may be perfectly adequate in the application considered. However if the required power level is raised to 15 watts, the picture changes. A vacuum-tube circuit delivering this power dissipates between 10 and 15 watts in the plate circuit alone, and the resultant temperature rise may seriously shorten life and prevent successful miniaturization of the equipment. The high efficiency that may be possible with the magnetic amplifier becomes a very important factor. Beyond 15 watts, the contrast become even greater, and the magnetic amplifier becomes the only possible choice in the majority of cases.

This suggests that the chief feature of the magnetic amplifier is its ability to handle large power levels at good efficiency, drawing power directly from the a-c line. The applications given below reflect this.

Servo motor, ranging in power levels from a few watts to the fractional horsepower class, are favorite actuators for control systems. The most common is the two-phase induction motor modified for the special torque speed characteristics required in positional servo loops. These motors take a-c power on their control windings and reverse their direction of rotation when the phase of the fundamental component of this voltage, in quadrature with the main field voltage, reverses. This control voltage is not necessarily sinusoidal, for the average torque produced is proportional only to the fundamental component. Although the output of a suitable magnetic circuit may not be sinusoidal, good design compromises are possible, and compact and adequate magnetic amplifier drives can built it. At higher power levels there is no other amplifier choice, because, aside from the reliability problem, the size and weight of a vacuum-tube amplifier with its associated power supply are generally prohibitive.

The older applications of the saturable reactor to the control of heavy industrial loads are still very much alive. These include lighting loads, electric furnace control, temperature control with feedback sensing, d-c current metering, d-c motor speed control, generator voltage control, and many others.

The above applications are the principal ones developed so far, chiefly because the field is still new and early development has been directed toward applications for which the magnetic amplifier presented the only reasonable approach.

Future development will probably consist in the refinement of existing circuits and their application, with increasing frequency, to equipments which have so far not used magnetic amplifiers. It can be expected that new circuits will be developed to resolve some of the serious problems still facing the designer of magnetic amplifiers. These engineering advances there must come the evolution of satisfactory production techniques to permit large-scale manufacture with good production control over end performance and reliability. It seems that, with much of the basic development accomplished in one decade, the future trend will be the introduction of the magnetic amplifier technique into a variety of electronic control.

Furthermore, there are problems where certain unique features of the amplifier are required, e.g., special transfer characteristics, inherent constant-current characteristics, dynamic-braking properties, substantially constant gain, action as a d-c/a-c or a-c/d-c converter, low-impedance or high-impedance output, special feedback characteristics, etc. Such features may be obtained by applying modified circuitry or by proper rating of different circuit components.