

# Computer-Aided Optimum Design of Magnetic Circuits with Permanent Magnets

ASHOK H. PRADHAN

**Abstract**—A computer-oriented method is developed for optimum design of magnetic circuits with permanent magnets. It consists of finding an electrical equivalent for the magnetic circuit and writing a computer program that evaluates the various circuit elements, solves the resulting network equations, computes the leakage and reluctance factors, and solves the design equations iteratively. The design can be coded out to satisfy criteria such as minimum magnet volume or minimum material cost. The program can also be used to obtain the expected performance of specified designs thus allowing the designer to evaluate his design ideas without iterative prototype building. The execution time is of the order of a few seconds, and the designer can use the program in interactive mode thus saving substantial engineering time.

## INTRODUCTION

THE PHILOSOPHY<sup>1</sup> behind computer-aided, or automated, design is illustrated in Fig. 1. The designer inserts the necessary specifications from a teletype into a digital computer. A program stored in the computer computes the design, which could be optimum according to a prespecified criterion. The required design parameters and the expected performance are printed out on the teletype. The designer inspects these and, if necessary, makes changes in the input specifications. When the expected performance is acceptable, a prototype is built and its performance is measured. This process is repeated until acceptable measured performance is obtained. Because of the computer in the loop, the design time is considerably shortened and the number of prototypes required is also reduced.

One such computer program is described elsewhere [1]. This paper deals with computer-aided optimum design of magnetic circuits with permanent magnets.

## Magnetic Circuit Design Using Permanent Magnets

The typical problem encountered in practice when designing magnetic circuits using permanent magnets can be stated as follows: "Find the magnet material and dimensions of the magnetic circuit having a desired geometry that will give the required flux density in an airgap of specified length at minimum material cost."

The geometry (shape, configuration) is usually dictated by the type of application. It could be one that is previously established or could be a novel one that the designer wants to try out. The required gap density is also dictated by the type of application, and usually has an acceptable range



Fig. 1. Computer-aided design philosophy.

Define the following quantities:

- $B_m$  flux density in the magnet axial section;
- $H_m$  magnetizing force corresponding to  $B_m$ ;
- $A_m$  cross-sectional area of the magnet transverse to direction of magnetization;
- $L_m$  length of the magnet along direction of magnetization;
- $V_m$  volume of the magnet;
- $B_g$  flux density in airgap;
- $A_g$  cross-sectional area of gap transverse to flux lines in the gap;
- $l_g$  length of gap along flux lines in the gap;
- $\sigma$  leakage factor =  $\frac{\text{total magnet flux}}{\text{useful gap flux}}$ ;
- $\tau$  reluctance factor =  $\frac{\text{MMF applied by magnet}}{\text{MMF drop in gap}}$ .

Then, magnetic energy supplied by the magnet over the demagnetizing region of the  $B$ - $H$  curve

$$\begin{aligned}
 &= \frac{1}{2} \text{MMF} \times \Phi_{\text{ax}} \\
 &= \frac{1}{2} (H_m L_m) \times (B_m A_m) \\
 &= \frac{1}{2} (B_m H_m) \times V_m.
 \end{aligned} \tag{1}$$

Therefore, in order to get a certain magnetic energy for minimum volume of magnet, the product  $B_m H_m$  for the magnet, commonly known as the "energy product," should be maximum. This is the starting point for design of magnetic circuits with permanent magnets. Practical limitations of the present operation of the magnet at its maximum energy point, is that one, since the energy product starts to decrease, the operating point should be as close as possible to the maximum. There are

Manuscript received March 17, 1972.  
The author is with the Westinghouse Research and Development Center, Pittsburgh, Pa.

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