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An artificial intelligence approach to the efficiency improvement of a universal motor

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Abstract

This paper presents a design approach for improvement of the efficiency of a universal motor, the type of motor that is typically used in home appliances and power tools. The goal of our optimization was to find optimal values of the independent geometrical parameters of the rotor and the stator of the UM with the aim of reducing the motor's main power losses—they occur in the iron and the copper. Our procedure is based on a genetic algorithm (GA), and by using it we were able to significantly improve the motor's efficiency. The GA proved to be a simple and efficient search-and-optimization method for solving this day-to-day design problem in industry. It significantly outperformed a conventional design procedure that was used previously.

Keywords: Universal motor; Industrial production; Efficiency improvement; Evolutionary/genetic algorithms

1. Introduction

Various home appliances, such as vacuum cleaners and mixers, as well as power tools, such as drills and saws, are generally powered by a universal motor (UM) (Sen, 1996). This particular type of motor has many advantages. A brief look at the *advantages* shows why the UM is such a popular choice for home appliances and power tools:

- it is a very powerful motor in relation to its small size;
- it has high starting and running torque;
- it has a variable speed that can be regulated in a simple way;
- it is inexpensive to manufacture.

In home appliances and power tools, it is very important that the energy consumption of the motor, i.e. its input power, is as low as possible, while still satisfying the needs of the user by providing sufficient output power. The ratio of the output power to the input power defines the efficiency of the motor, which can be improved by reducing some of the main power losses in the motor, i.e. those that originate in the iron and the copper.

In this paper, we propose a method for reducing these power losses by optimizing the geometry of both the rotor and the stator. Because of the high magnetic saturation of the iron in a UM, the problem is a highly non-linear one. For this reason, we adopted an artificial approach using a genetic algorithm (GA) (Bäck, 1996; Goldberg, 1989). This algorithm has already proved to be very efficient in a wide range of different optimization procedures where the exact equations are not available or some non-linearities are present (Drechsler, 1998). In addition, due to its simplicity, the initial investment in such a method is low.

2. Basics of the universal motor

UMs (Fig. 1) are built to operate with either a DC or an AC power supply. A UM uses a commutator, and its

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basic construction resembles the design of a DC series motor. A UM performs like a series motor—the same current, regardless of the power supply, passes through both the armature (rotor) windings and the field-excitation (stator) windings via the brushes in one continuous path. Fig. 1 shows the rotor and the stator parts of a UM.

2.1. Geometry of the rotor and the stator

The rotor-and-stator unit of a UM is constructed by stacking the rotor/stator iron laminations (see Fig. 2). The shape and the profile of the rotor/stator lamination are described by several two-dimensional (2D) geometrical parameters. There are two types of parameter: the invariable and the variable. Invariable parameters are fixed; they cannot be altered, either for technical reasons or because of the physical constraints of the motor. See Table 1 for details of geometrical parameters.

In our case, there are 12 mutually independent variable parameters that we can optimize. However, some important problem constraints have to be taken into account:

- The parameters should be changed simultaneously (both independent and dependent parameters) to achieve proper electromagnetic conditions in the material.
- Each parameter dimension should only be varied within a predefined limit.
- Parameter transformations and their evaluation should be done as quickly as possible.

2.2. Efficiency of the motor

The efficiency of a UM is defined as the ratio of the output power to the input power, and it depends on various power losses, which include:

- Copper losses: the joule losses in the windings of the stator and the rotor.
- Iron losses: including the hysteresis losses and the eddy-current losses, which are primarily in the armature core and in the saturated parts of the stator core.
- Other losses: like brush losses, ventilation losses and friction losses.

The overall copper losses (in all stator and rotor slots) are as follows:

$$P_{\mathrm{Cu}} = \sum_i (J^2 A \rho l_{\mathrm{turn}})_i, \quad (1)$$

where i stands for each slot, J is the current density, A is the slot area, ρ is copper's specific resistance, and l_{turn} is the length of the winding turn.

Because of the non-linear magnetic characteristic, the calculation of the iron losses is less exact. The iron losses are separated into two components: the hysteresis losses and the eddy-current losses. Consequently, a motor's iron losses can be expressed by the following equation

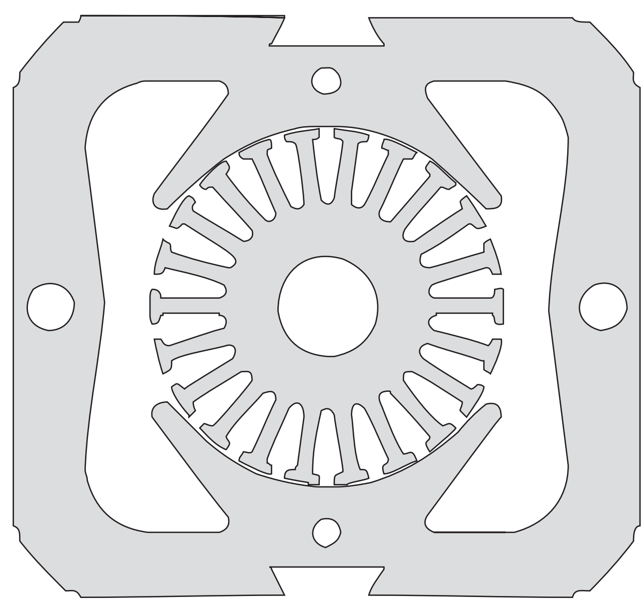

Fig. 2. Stator and rotor laminations of a UM.

Fig. 1. UM used in a vacuum cleaner with rotor and stator parts.