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A Novel Technique for Control of Electromagnetic Devices: Liquid Metal Contact Changer

APPLIED ELECTROMAGNETICS AND CIRCUIT THEORY

Abstract

Changing parameters in the electromagnetic devices has been known as a common technique to reach the appropriate system behavior. Usually, a changing tool and a control circuit collaborate to implement the desired control criteria of the system. Most of the time a set of feedback signals is needed to provide system information for the control circuit. This set sometimes includes important information from the changing device to prevent instability of the system. These signals are usually driven from the converted built-in quantities of the electromagnetic device like voltage and current (in accordance with magnetic flux density and magnetic flux intensity) and are processed to make an appropriate decision. Examples of such systems can be seen in some of FACTS devices (e.g. current and voltage controlled reactors); transformers on load tap changers (OLTC), motor starters, etc. In some of these systems it is feasible to directly use the built-in parameters as feedback and abstain from converting the parameters. Using this technique may allow the designer to amalgamate or even eliminate some parts of the above mentioned system. This paper intends to present a new technique for control of electromagnetic devices which essentially applies the Lorentz force to change the required parameters. In this technique, the control circuit and the changing tool are amalgamated and so they can directly use the system built-in quantities as feedback information. Since Lorentz force is the driving force of the changing tool, the magnitude and the direction of current and magnetic field vectors and their mid-angle are counted as the main control factors. The main idea of the proposed technique is using a movable conducting medium which is a part of the main circuit and carries current under the magnetic field effectiveness region. This conducting medium would move if the driving Lorentz force overcomes the various resistant forces. Therefore the resistant forces can also be used to control the parameters. In fact the design of the described device is the art of compromising between the deriving and resistant forces to make the required control on the system. The resulted movement can be used to change the circuit arrangement (e.g. number of winding turns in an electromagnetic device) and accordingly create the desired system control. In this paper, the proposed technique is explained and possible implementation difficulties are discussed accordingly. Finally some suitable countermeasures are suggested.

Key words: Electromagnetic Device (EMD), Liquid Metal, Tap Changer, FACTS Devices

1- Design Philosophy

The main idea of the design is to reduce the possible risk/error of the control circuit and measuring devices. As a side effect of this idea, the additional costs and required space of the control device may also be reduced or even eliminated. In order to implement the idea some basic quantities of the system shall be considered rather than converted quantities. In this regard, the built in quantities of the electromagnetic devices are the best choices and have been used in some other techniques. Suchlike we can see some electromagnetic systems in which the saturation effect of magnetic materials has been chosen as a control factor [1]. In another technique magnetic circuit structure of the device is changed in order to change the required parameter of the system [2]. Since we are going to amalgamate the control and actuating systems in the present technique, exact movements have to be made in the device and therefore some well known rules of electric machines theory will be used in this technique.

2-Technique description

Figure (1) illustrates a simple structure of the technique. As it can be seen a segmented conducting surface is separated from another conducting surface via solid isolators. As a simple envision of the system geometry, we can imagine a rectangular cubical which is made of four sides of insulating materials and two of conducting solid metals. One of the metallic sides is segmented and separated into smaller parts via solid insulating materials (e.g. mica). These small parts are connected to the various parts of the circuit (e.g. different taps of the winding) which are to be connected to the other conducting surface via movable conducting medium. Liquid metal conducting medium has been used in a relatively similar structure which has been introduced as a nonlinear resistive current limiting device [3]. In the present technique, liquid metal is also selected as movable conducting medium and therefore its characteristics play an important role in the control behavior of the system.

Figure 1-Schematic of contact changing medium

Sufficient amount of liquid metal (e.g. GalinStain) is used to stuff the space gap between each conducting segment and another integral conducting surface. This is performed in such a way that it can provide proper conductivity between the above mentioned metallic surfaces during operation. This vessel is located in a suitable place which magnetic field can vertically (or any other angle) pass through the current flowing in the movable conducting medium. The magnetic

field may be the main field of the electromagnetic device or it may be a proportional sample of the main field. This association causes a movement in the liquid metal during current flow and can be used to create a desired change in the circuit by contacting the liquid metal with a new segment which is connected to another part of the circuit. The liquid metal stops movement when the algebraic sum of the restrictive forces and the driving forces becomes zero. Surely the liquid metal won't stop if there is not enough restrictive force to make a negative acceleration. In order to prevent such a manner, the vessel geometry and its position should be determined very carefully considering different types of the resistant forces which exist in the system. In the other words, these resistant forces must be used just like control factors. Three different types of resistant forces may exist in the proposed structure:

- Gravitation Force
- Friction & Shear Stress
- Environmental Pressure

Each of these forces affects the design of system in special concerns. For example gravitation force directly affect the design of main geometry of the vessel (i.e. position and of the vessel with respect to magnetic field direction, direction of movement of liquid metal, etc.). Some of the design parameters may be affected by considering to the several types of resistant forces and compromise may be needed.

3 Design considerations

As described before, control factors can be divided into two different groups of *Driving Forces and Resistant Forces*. Hereunder, some important details of the design will be discussed considering these two groups.

3.1 Driving force determination

Lorentz force is simply calculated via its famous formula:

$$F = J \times B \qquad\qquad (1)$$

Current density and magnetic flux density vectors and their respective position are obviously the main control factors which can be tuned to reach the desired control. Rate of current density is depended on the amplitude of the current flowing in the liquid metal part and the cross section which current is flowing in. The former is clearly depended on the circuit arrangement and the latter is depended on the geometry of the vessel and spatial characteristics of liquid metal conductivity. This makes the problem relatively complicated since the liquid metal of concern is moving during conduction and hence we face a *Moving Mesh problem.*

3.2 Resistant forces determination

Three different types of resistant forces which were introduced before can be calculated via solving the Navier-Stokes equations for moving fluid. This may also seems relatively difficult to solve but there are some simplifying assumptions which can be supposed. Essentially the simplified forms of fluid mechanics equations are used for the first stages of the design. Some of the resistant forces control factors which should be considered as design parameters are as follows:

- Geometry of Liquid Metal vessel (cross section area, shape of insulators which separate the segments, etc)
- Mass and volume of Liquid Metal
- Gas insulation and liquid metal physical properties (density , viscosity, specific weight, etc)
- Effective area of each segment

While the liquid metal is touching a specified segment, no change is occurred in the circuit arrangement till another segment is touched by liquid metal. Some times it is useful to increase or decrease the traveling time of the liquid metal on a special segment.

- Slope of movement with respect to the gravitation force direction

Each of these factors may be used to fulfill the control criteria to some extents. For example some times it is necessary to increase the resistant force gradually in order to maintain the stability of the movement. This could be performed by designing a relatively complicated vessel which increases the gravitation force affecting on the liquid metal via changing the direction and slope of movement. Figure (2) illustrates a simple schematic of such design.
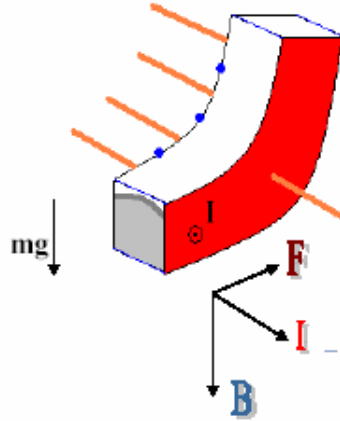

Figure 2- Schematic structure useful to increase resistant force gradually

4 Technical challenges and problems

There are various technical punctilios which should be considered during design optimization. Hereunder some of them are listed.

- Current commutation during contact changing

During liquid metal movement, undesired currents may flow between contacts and therefore additional forces may appear during commutation. Figure (3) illustrates the described condition for a typical simple design of the contact changer. Equivalent circuit of the system is also shown and three switches are defined to analysis the time differences between the forces which may occur.
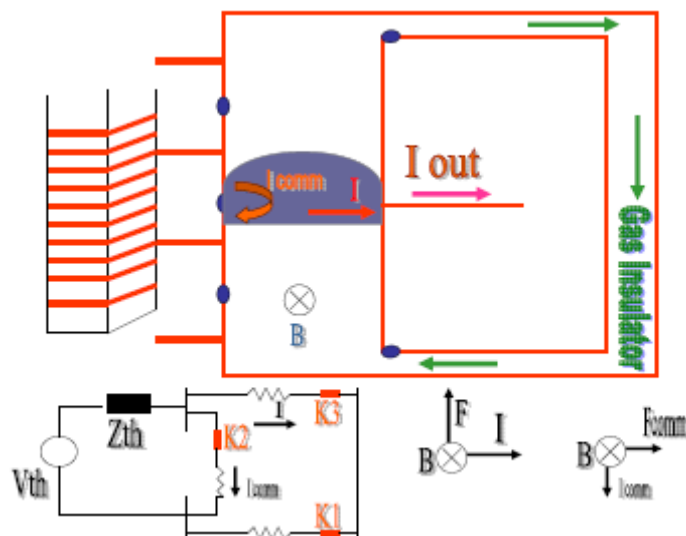

Figure 3- Possible condition, equivalent circuit and additional forces during current commutation in a typical simple design

- Dielectric strength of the gas insulation

A considerable voltage may appear across an opened contact (segment) and the outgoing conductor which is connected to another segment (via liquid metal) with different voltage. It is necessary to make appropriate clearance distances between outgoing conductor and segments. Increasing liquid metal volume is not a proper technical countermeasure since it will increase the required driving force. It seems that using an insulating gas with high breakdown strength is a better way to solve the problem.

5 Conclusion

A new technique for control of electromagnetic devices has been presented in this paper and its basic theoretical rules have been described. Various affecting design parameters of the driving and resistance forces were explained and accordingly the important technical punctilios and their respective countermeasures have been presented. Although the manufacturing of the first prototype has not been finished yet, elementary simulation shows that the design could be used in low power EMD with relatively high performances. But in high power EMDs which may need to larger amount of moving liquid metal and/or larger gaps between the metallic contacts, more efforts shall be made to overcome the molecular disassociation of liquid metal during the movement. Other practical problems may also be occurred after performing appropriate functional tests on the first prototype. But since there are many variable design parameters in the proposed technique, hopefully most of them can be solved and the prototype will be improved.

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[2] Patrick; Stephen L. US patent No.656313
[3] K. Niayesh and F. Konig, European Patent application No. EP03405519.4

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