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Management of Linear Switched Reluctance Generator Without a Translator Position Sensor

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Abstract: This study describes the way of non-sensor management of linear switched reluctance generator, based on analysis of characteristics of phase current impulses with fixed duration.

Key words: Regenerative shock absorber, linear reluctance machine, translator's position sensor, management, reluctance generator

INTRODUCTION

The problem of energy efficiency in automobiles is becoming more important and continuing to be the focus of attention of leading auto manufacturers. One of the alternative solutions is regeneration of mechanical vibration energy of car body into electrical energy. In particular, one of such solutions is application of regenerative shock absorber based on linear electromechanical converter as a part of car suspension, including the active suspension system. The main advantage of the linear electric machine is an immediate transformation reciprocating motion energy into electric energy without intermediate stage. Such kind of devices can be applied not only in the vehicle suspension system but also in the suspensions of a driver's seat, a cabin and a motor.

As a linear electrical machine for regenerative shock absorber it is possible to use a switched reluctance generator or a generator with permanent magnets. In terms of specific power the generator with permanent magnets has an advantage, however, the simpler design and the lack of expensive magnets make the inductor generator more attractive in terms of price.

For operation of switched reluctance generator it is required the translator position sensor (the rod of shock absorber) which ensures the switching accuracy of phase windings. It is possible to apply Hall sensors, electrooptical component, inductor sensors or other types. The position sensor generates impulses depending on the translator position while the control system of generator's converter, based on these signals, manages the power transistors. Therefore, we come to the needed operational modes and required working conditions for switched reluctance generator. The exclusion of the translator position sensor allows us to optimize the final cost of shock absorber, to simplify the design, to increase the specific power by means of expanding the work space of generator. At the same time the translator position is defined indirectly by electrical parameters available for measuring: voltage and current of motor stator (Schroder, 2001; Arakelyan and Glukhen'kii, 2003; Lisowski and Semenov, 2004; Adadurov, 2008).

MATERIALS AND METHODS

Method for determining the position of translator: In order to detect the translator position during moving it is proposed to use the characteristics of phase current impulses Δi_{ph} of fixed duration Δt. In addition, the main information parameter is the point of current impulse minimum. Figure 1 shows the sequence of current impulses $\Delta i_{ph}(t)$ in three-phase linear switched reluctance generator. For comparative evaluation it is also presented the signals of position sensors of appropriate phases PS_A, PS_B, PS_C.

Inductivity of generator phase winding L_{ph} cycles while the tooth of translator moves forward and backward to stator tooth. Due to this fact, at a different translator position relative to the stator for the same time intervals Δt and under the constant voltage supply of generator, the values of current impulse amplitudes Δi_{ph} are inversely proportional to instantaneous values of phase winding inductivity. Current impulse frequency is defined by the time of current decay in phases till zero as well as by acceptable switching frequency of power transistors in the converter controlling the linear generator. According to the series of current impulses Δi_{ph} (t), supplying each

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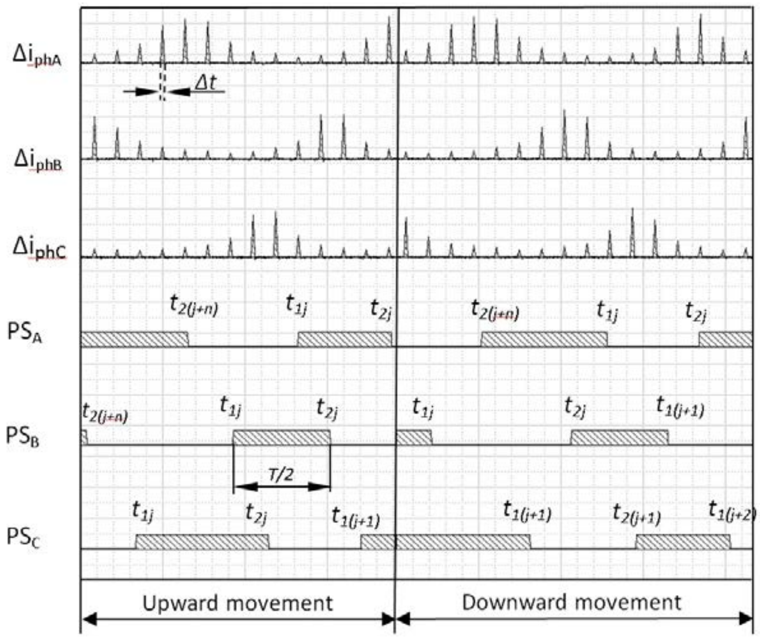

Fig. 1: Testing oscillograms of phase currents of the linear switched reluctance generator

phase, it is shown the sequence impulse amplitudes related to the displacement value of generator's translator against the stator $\Delta i_{min\ ph}(\theta)$ for the full period of each n-phase. This data is recorded to the control system memory (Fig. 2). Additionally, it is recorded the sequence of phases switching when upwards and downwards moving of inductor generator's translator (Fig. 3) in each 60 el. deg.

The translator position is detected by amplitudes of single current impulses of fixed duration in all phases of machine (Fig. 4). PS'_A, PS'_B, PS'_C are the signals of rotor position (phase A-C), simulated by control system. In this case the time moments t_{1j} of current rise start for j-switching is defined by amplitude of current impulses Δi_{ph} (t) of fixed duration Δt and frequency determined by winding inductivity, switching frequency of inventor's transistors f_{tr} and a control system response, i.e., $t_{1j} = f(\Delta i_{min.\ ph}, \Delta t, f_{tr})$.

Under the given movement direction and by means of phase sequence tables we identify the required working phase or two phases. In case of original switching of two phases, the deactivation of required phase, according to on and off phase sequence and depending on movement direction is performed in 1/6 of phase period (Fig. 3). The initial value of the period, measured in time cycle of a microcontroller is set as maximum.

After detection the required working phase (phases), the current impulses are supplied only to non-working phases (phase), the switching time of which should be defined (Fig. 4). The moment of next switching phase (for example, phase «B») is determined by the break point at the maximum point of dependency of current impulse amplitude sequence. In this case the time of current supply termination to the phase (phase «B») is defined by the time moment of opening the previous (phase «A») and present phase (phase «B») (Fig. 4) in accordance with the following equation:

$$t_{B2j} = t_{A1j}+(t_{A1j}-t_{B1j})/2$$

The computational error of switching time of sequent phases falls within the limits of time interval Δt_1 (Fig. 4), defined by acceptable switching frequency of power devices of the converter. Thereafter, when next switching, having the phase operating period T and time interval Δt_1, the switching time for each j-switching is corrected (Fig. 4). In this case:

$$t_{B1(j+1)} = t_{C1(j+1)}+T/3-\Delta t_1$$

and current impulses for detection of switching time of machine phases and the rate of movement are supplied only to one generator phase "A". In next periods the time intervals of the sequent current rise in the phase are defined by the closing time of phases:

$$t_{B1(j+2)} = t_{A2(j+1)}+(t_{A2(j+1)}-t_{B2(j+1)})/2$$

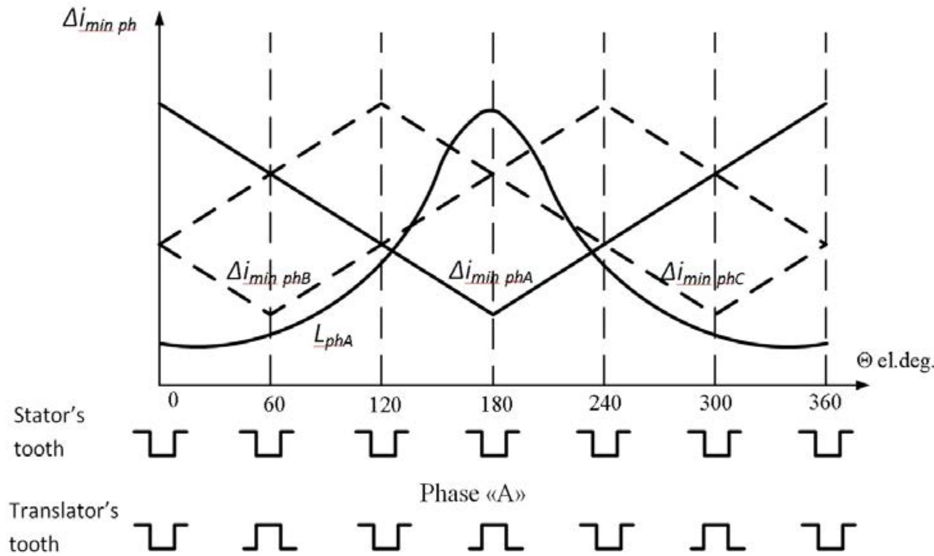

Fig. 2: Graph presented the tabular dependency $\Delta i_{min\ ph}$ (θ) to indicate the translator position during movement in phase "A"

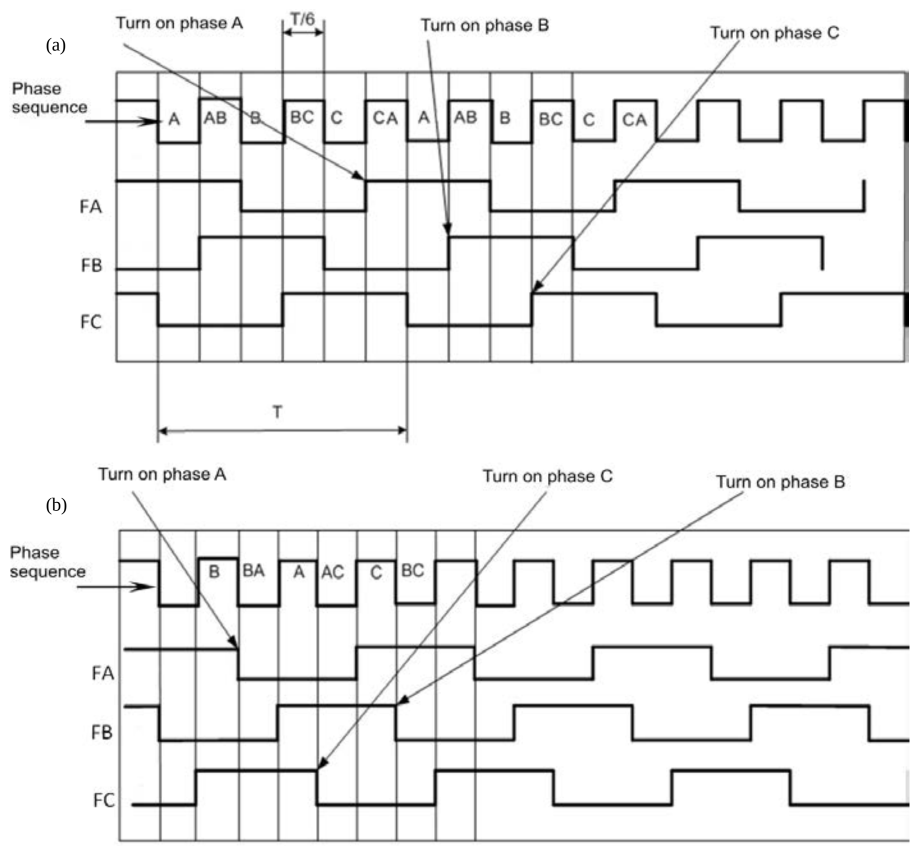

Fig. 3: Sequence of stator phase switching: a) upwards moving of the translator and b) backwards moving of the translator

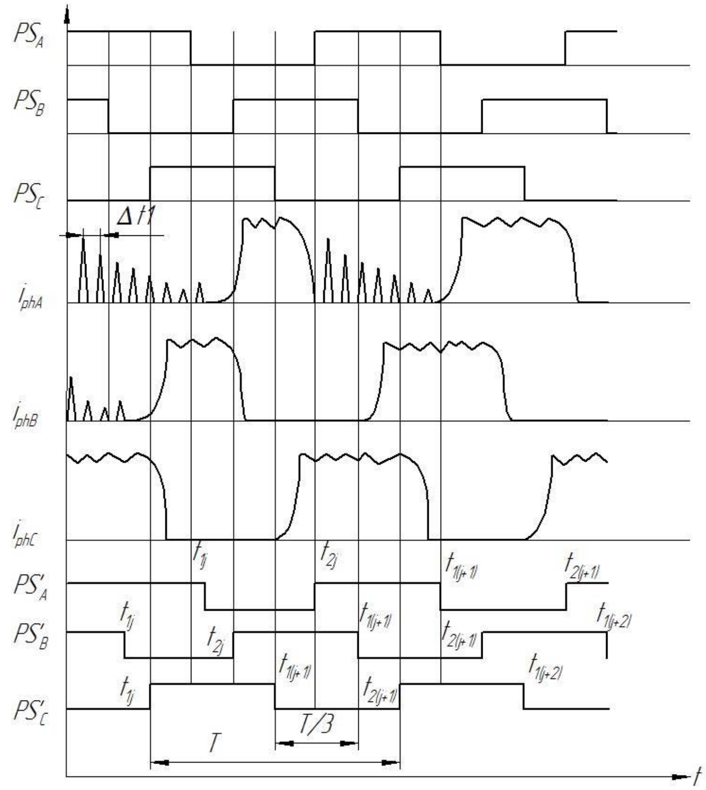

Fig. 4: Oscillograms of generator current phases (downwards moving of the translator)

RESULTS AND DISCUSSION

Having such way of management, it is possible to ensure the acceptable accuracy (1-3 el. deg.) for determination of phase switching time of linear switched reluctance generator under the rates of translator movement which are typical for operation of regenerative shock absorber as a part of active suspension.

The proposed way of non-sensor management of linear switched reluctance generator, based on analysis of characteristics of phase current impulses with fixed duration, allows us to define with acceptable accuracy the position of the translator.

CONCLUSION

So, it makes possible to remove the position sensor and therefore, to optimize the final cost of shock absorber, to simplify the design, to increase the specific power by means of expanding the work space of linear reluctance electrical machine.

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