

Complex analysis of electromagnetic machines for vibro-impact technologies

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Abstract. For the implementation of high-energy impulse technologies of mechanical shock methods of secondary rock destruction, electromagnetic machines of vibro-impact action are of particular interest. Linear synchronous electromagnetic impact machine designs as a part of progress trend are considered where the head reciprocal motion is synchronized with 50 Hz power source pulses frequency applied to a winding or a system of windings. On the basis of identified differences of the head forced mechanical oscillation processes, merits and demerits of the work cycles of single or two-winding synchronous machine design variants are analyzed. Synchronous electromagnetic machines of a new design and principles of their control in a work cycle are presented. The specific half-wave interleaving of voltages applied to the windings allows reducing current amplitude and the influence of the impact drive on the power grid. To improve forced oscillation mode stability and precision, the new engineering solutions improving machines performances and exploitation conditions are proposed.

1. Introduction

For the implementation of high-energy impulse technologies of mechanical shock methods of secondary rock destruction, electromagnetic machines of vibro-impact action are of particular interest. Impact electromagnetic machines are widely applied in industry [1–3]. Low-frequency impact technologies implementation is accompanied by spreading linear synchronous electromagnetic machines. The reciprocating head of such machine as an impact mass is synchronized with 50 Hz power line voltage pulses applied to a winding or a system of windings [4, 5].

As the mechanical system constantly supports forced head oscillations this class of machines is distinguished by higher energy conversion efficiency when energy is passed by an impact [5–7]. The most of such machines generate impact energy in the range of $A_{im} = 2.5 \dots 15 J$ while impact frequency is not more than $50 s^{-1}$ or $3000 min^{-1}$.

Head mechanical oscillations synchronous frequency is commonly equal to power line frequency or multiple of it. Depending on the electromagnetic machine control method, its total operating cycle consists of one or several periods of power source voltage. Hence, if power line frequency is $f = 50 Hz$, then head impacts frequency is $n_{im} = f/2p [s^{-1}]$ and the total operating cycle duration is $t_c = 2p/f [s]$, where $2p = 1, 2, 3, \dots$ is power voltage periods per one operating cycle.

2. Synchronous machines schemes analysis



The purpose of the investigations described in this paper is the analysis of operating processes in impact linear synchronous electromagnetic machines and implementation of control methods in the machine operating cycle.

Some variants of synchronous impact electromagnetic machines with short analysis of interaction between electrical, magnetic and mechanical systems are considered in [8]. Reciprocating motion of the impact mass is similar for many types of machines.

Figure 1–6 show the variants of synchronous impact electromagnetic machines schemes and the respective diagrams of head travel x , winding voltage u and current i . The windings are powered by a 50 Hz 1-phase source. In figure 2–6, u_{tr} , i_{tr} stand for travel voltage and current, and u_{rv} , i_{rv} stand for reverse ones.

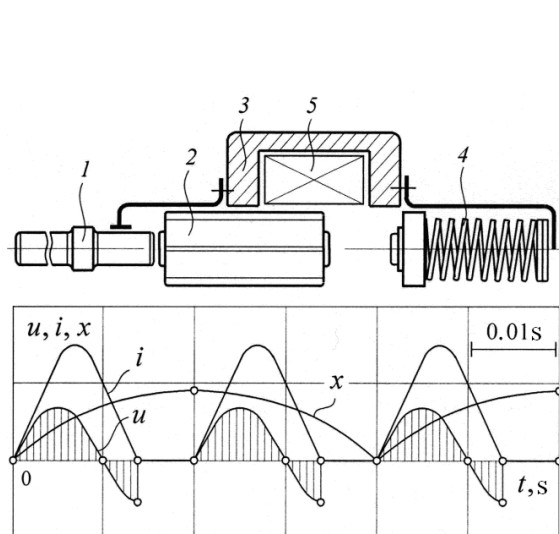


Figure 1. Synchronous electromagnetic machine with head two-side free running-out in winding

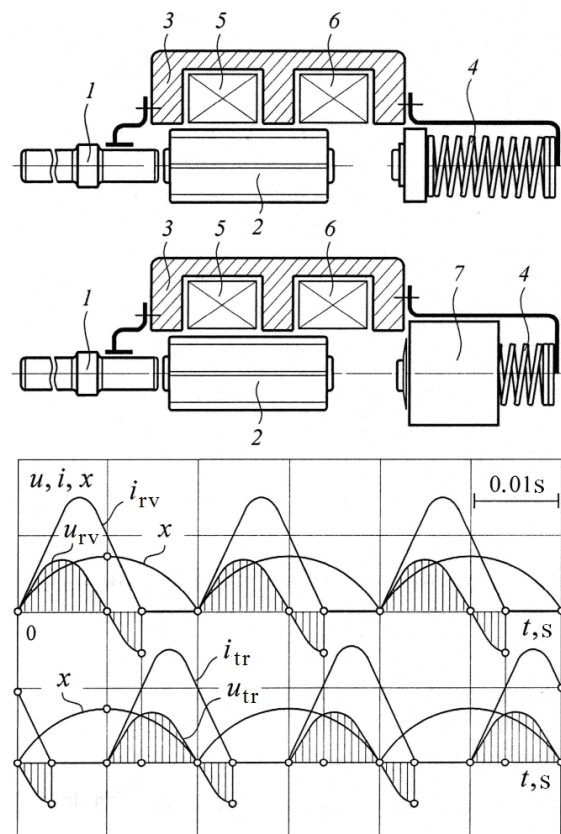


Figure 2. Synchronous electromagnetic machine with head under constant electromagnetic forces

The synchronous machine impact node, integrating magnetic and mechanical sub-system elements, consists of the following standard elements: tool – 1; head (forming the impact mass) – 2, magnetic core – 3, reverse spring buffer – 4, inertial converter heavier than head combined in some cases with the reverse spring buffer – 7, magnetizing winding – 5 (figure 1) or travel magnetizing winding – 5 and reverse magnetizing winding in figure 2–6. The existing engineering solutions in such machines are implemented for supporting synchronous mode stability. Among single winding schemes the synchronous electromagnetic machine with head two-side free running-out has been brought into practice (figure 1).

The scheme of this machine was applied in handheld impact tools MC-15, MC-16 [1].

The total operating cycle of the machine impact node consists of voltage periods, providing synchronous impact frequency $n_{im} = 25\text{ s}^{-1}$ (1500 min^{-1}) and operating cycle duration $t_c = 0.04\text{ s}$.

The machine is powered by a 1-phase source through a half-period rectifier. The head travel towards the tool is executed by winding electromagnetic forces and spring buffer elastic force. Reverse is made only by winding electromagnetic forces. Two-winding schemes are distinguished by wider capabilities of operating cycle implementation. Synchronous electromagnetic machines with the head spring and inertial reverse became mostly used in practice (figure 2).

Such schemes were applied in impact nodes of the electric tools SC-2, IE-4207, IE-4709, IE-4724 and ERP-1000 [1]. The operating cycle is implemented by the two-winding system accelerating the impact mass by electromagnetic forces in travel and reverse directions [1–3].

The total impact node operating cycle corresponds to one voltage period, providing synchronous impact frequency $n_{im} = 50 \text{ s}^{-1}$ (3000 min^{-1}) and operating cycle duration $t_c = 0.02 \text{ s}$.

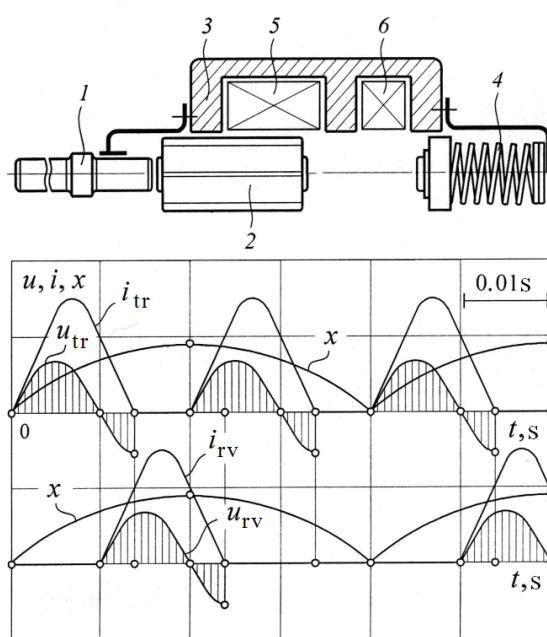


Figure 3. Synchronous electromagnetic machine with head running-out in travel winding

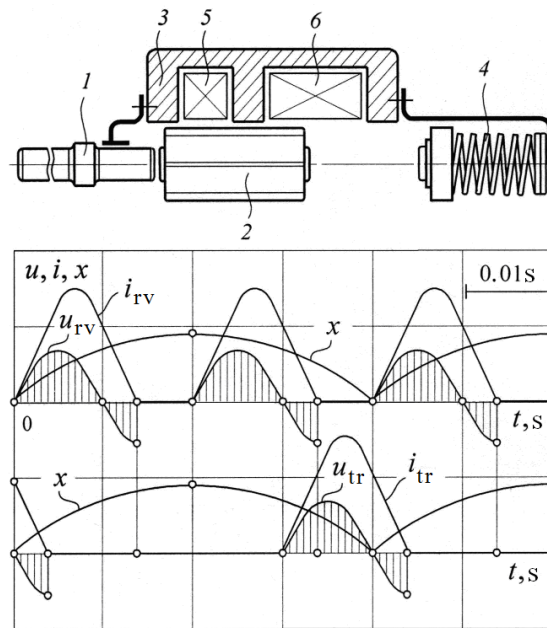


Figure 4. Synchronous electromagnetic machine with head running-out in reverse winding

The head reciprocal motion is synchronized by voltage half-waves of alternate polarities generated by the half-wave rectifier at constant electromagnetic forces acting on the head.

Impact frequency and current can be reduced in the synchronous machine with head free running-out in the travel winding (figure 3). It is also possible if head free running-out takes place in the reverse winding (figure 4).

The head gets necessary kinetic energy from three current pulses per one total operating cycle. Control of the scheme in figure 3 is discussed in detail in [8].

Changing polarity sequence of voltage half-wave application to the travel and reverse winding can transform the scheme in figure 3 to the scheme in figure 4.

If power source frequency is 50 Hz, then the total operating cycle corresponds to two voltage periods, providing synchronous impact frequency $n_{im} = 25 \text{ s}^{-1}$ (1500 min^{-1}) and operating cycle duration $t_c = 0.04 \text{ s}$.

In the scheme in figure 5 necessary head kinetic energy is accumulated from three current pulses per one operating cycle. To increase machine impact power [7, 9], the control method has been proposed. The essence of this method is in applying the first two voltage half-waves of opposite polarities to the reverse winding and the third half-wave to the travel winding. Such half-wave

sequence is a periodic one with no pause between cycles (figure 5).

The scheme in figure 5 is different from the schemes in figure 3 and figure 4 because of synchronous impact frequency $n_{im} = 33.3s^{-1}$ (2000 min^{-1}) and operating cycle duration $t_c = 0.03s$.

Figure 6 shows the operating cycle with head free running-out in the travel and reverse winding. The free running-out is implemented by the pause between half-waves applied to the travel and reverse winding when the head is moving mechanically towards the spring buffer or tool [1]. In the proposed control method both windings are used twice per one operating cycle, and the head accumulates necessary kinetic energy from for current pulses.

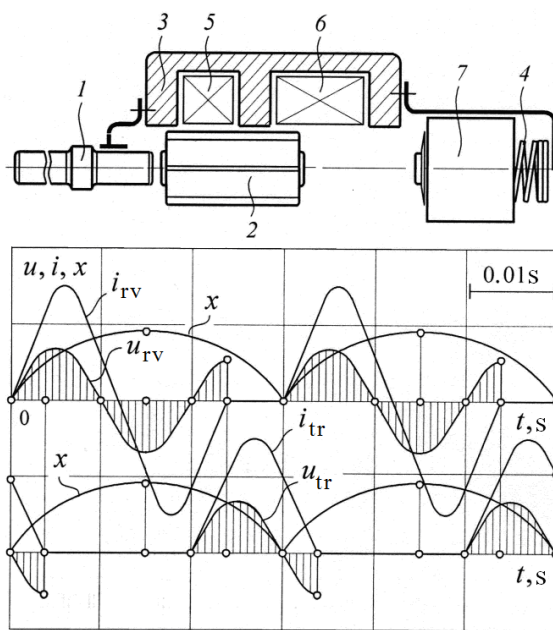


Figure 5. Synchronous electromagnetic machine with head inertial reverse and reduced impact frequency

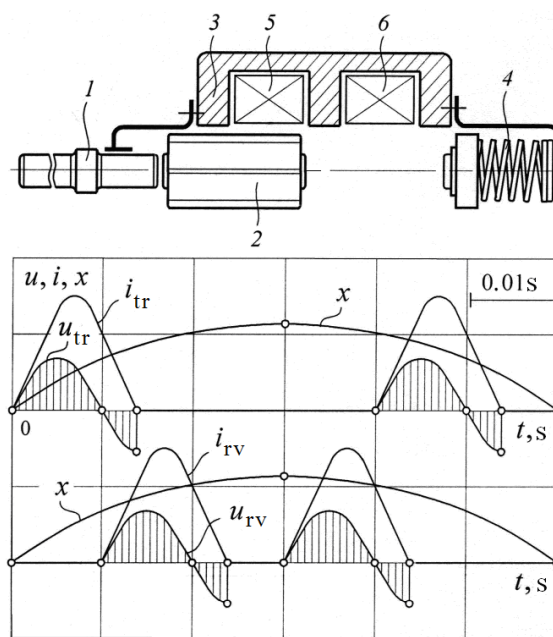


Figure 6. Synchronous electromagnetic machine with head free running-out in travel and reverse windings

The total operating cycle of the impact node is performed during three voltage periods, providing synchronous impact frequency $n_{im} = 16.7s^{-1}$ (1000 min^{-1}) and operating cycle duration $t_c = 0.06s$.

The mathematical proof of the investigation results (figure 1–6) is stated in detail in [2–4] as energy conversion processes description for the total operating cycle.

3. Schemes variants analysis

As it follows from the synchronous electromagnetic machine schemes analysis, the spring buffer or the inertial converter combined with it allows limiting current amplitude and reducing electromagnetic machine influence on the power line. As the head is not meant to be stopped and held in one of the extreme positions, then electromagnetic machine efficiency can achieve 40%.

The advantage of the scheme in fig. 1 improving energy conversion efficiency is in possible total elimination of head electromagnetic braking.

Stable operating modes of the scheme in figure 2 can be achieved by constant electromagnetic forces acting on the head. If there is no precise mechanism to tune forces oscillations and electromagnetic braking occurs, impact energy transmission efficiency becomes a bit lower.

To improve forced oscillations tuning accuracy and stability, one solution has been proposed in [1].

A decrease of current amplitude and impact node influence on the power line by increasing impact

frequency is possible with the schemes where the impact mass is accelerated during three half-waves (figure 3–5) or four half-waves (figure 6). More detailed analysis of the synchronous machines schemes in figure 3–6 is embarrassing as their operating cycles are almost not studied.

Two-winding schemes in the forced oscillations mode permit to reduce impact frequency until 16.7s^{-1} .

After all, operating cycles implementation at lower frequency is possible if windings quantity is increased. However, as the forced oscillation mode is difficult to support, three and more windings systems are not widely spread in practice.

4. Conclusion

Practical implementation of the newly proposed operating cycles of impact linear synchronous electromagnetic machines and methods to control them permits to reduce extremely current amplitude and to decrease electric drive effect on a single-phase power line.

Possibility to use the intermediate conversion of moving masses kinetic energy to spring potential energy in the operating cycle and then to convert potential energy to impact kinetic energy allows one to achieve impact power more than pulse source power.

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