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piezoelectric engine, SP-F model

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THE NEW ASPECTS OF PIEZOELECTRIC REVERSE LINEAR ENGINE

At the end of 20 th century the intensive development of material and genetic engineering and molecular biotechnology will require modern microrobots and precise manipulators with the possibility of carrying out elementary operations inside of crystal or in kernel of the elementary lively cell.
The successive ending of the scientific works on the thorough study of the piezoelectric wave – resonator will enable to construct prototypes of the piezoelectric reverse linear engine SP – F/L. It will be important for the development of piezomechatronics, biocybernetics, automation and robotization of the elementary advanced nanotechnologies which are steered digitally in automatized productive systems (APS).

NOWOCZESNE ROZWIAZANIE PIEZOELEKTRYCZNEGO SILNIKA FALOWEGO

W ostatnich latach wraz ze wzrostem automatyzacji obserwuje się zainteresowanie nową generacją ultradźwiękowych napędów elektrycznych. Zakończenie prac naukowych nad rozpracowaniem piezoelektrycznego rezonatora z propagacją fali biegnącej, pozwoliło na zbudowanie prototypu rewersyjnego piezoelektrycznego silnika falowego SP–F. Wstępne wyniki badań nad modelami SP–F rokują osiągnięcie dobrych parametrów elektro – mechanicznych oraz możliwość cyfrowego ich sterowania przy pomocy wysoko scalonych i zminiaturyzowanych systemów piezoelektronicznych. Opracowane układy sterowania powinny sprostać wymaganiom konstruktorów mechaniki precyzyjnej z zakresu mikrotechniki.

1. INTRODUCTION

Intensive development of material and genetic engineering and molecular biotechnology at the end of 20th century require modern microrobots and precise manipulators with the possibility of carrying out elementary operations inside of crystal or in kernel of the elementary live cell.

Conventional electromagnetic engines and transducers, with elementary step of rotary movement measured in minutes and of linear movement measured in tenths of millimeters, can't match increased requirements of precision mechanics designers in "micro" range and biotechnologists down to the "nano-technique" level.

Appearing of a new generation of ultrasound electrical engines [2,3] and successive finishing of scientific works on development of piezoelectric wave resonator which make use

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of longitudinal oscillations – in a standing wave regime with propagation of running wave - allow to assemble prototype of piezoelectric wave engine (SP-F).

Initial SP-F investigation results promise for good electromechanical parameters and possibility of electronic, digital control of this engines with no superfluous mechanical devices to get reverse movement.

2. PIEZOELECTRIC WAVE ENGINE (SP-F) WITH THREE-PHASE RESONATOR

The first wave engine model has been assembled basing on disk resonator with utilization of radial longitudinal wave (Fig.2).

This three-phase oscillator with spatial offset of $\Delta\lambda=\lambda/3$ ($\lambda=\pi * D_0$), supplied by three-phase alternating current ($\Delta\varphi=2/3*\pi$) with resonant frequency f_0, generates ultrasound rotational wave, which linear velocity on the micro level one can calculate from

$$v = f_r \lambda$$

After cutting and unfold this disk resonator one can get piezoelectric, three-phase, ultrasound wave resonator with theoretically any length L:

$$L = n \lambda$$

where:

v_c – direction and velocity of acoustic wave propagation,
v_b – direction and linear velocity of runner.

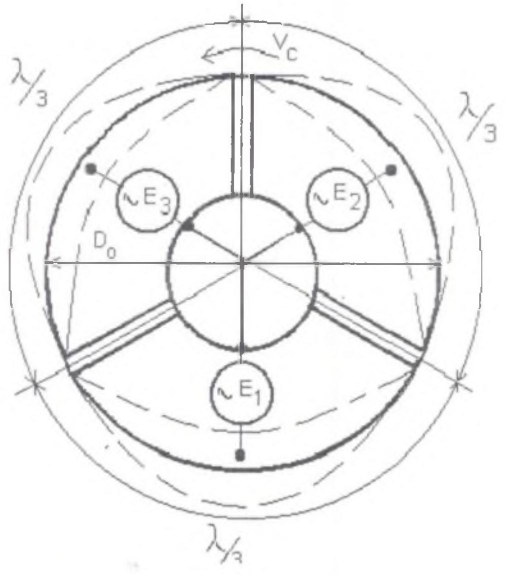

Fig.1. Piezoelectric three-phase wave resonator

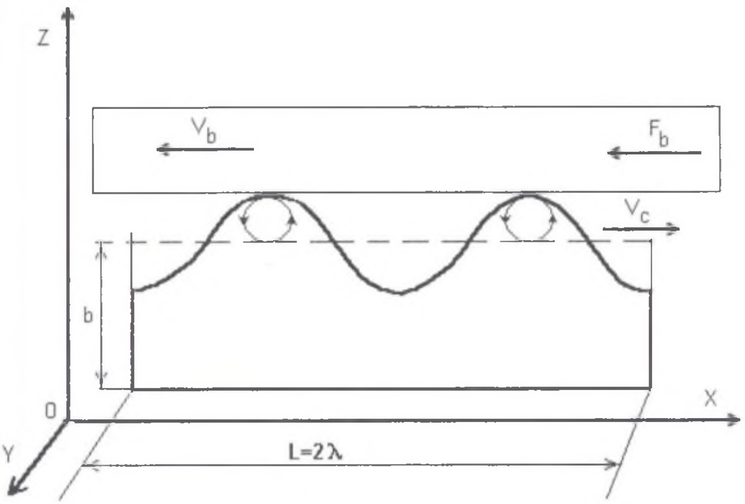

Fig.2. Kinematic model of two-wave SP-F/L

Making use of frictional action of kinematic pair coupling, one can transform oscillator wave movement to rotary movement of rotor or linear movement of runner in piezoelectric linear engine with wave resonator (SP-F/L). On principle of its work the engine is reverse like analogous conventional asynchronous or self-locking engine considering the contact way of work, which is utilized in its impulse-step work mode.

SP-F/L distinctive feature is zero contact angle between runner and wave resonator α_k = 0, which implies precise manufacturing and implementation of kinematic pair contact surface, and optimum selection of frictional material for cover of piezoceramic, protecting it against damage and wear.

Oscillator without load elementary step on micro level depend on driver resolution, minimum SP-F/L supply voltage impulse, and is in the range of 0 to some nanometres and on the macro level depend on runner or movement concentrator inertia.

Frictional pair wear approximation of Δs = 0.1mm in 5000 work hours in piezoelectric ring engine suggest 10 000 – 20 000 work without damage considering permanent gravitation runner pressure to waveguide (0 – 100) N and lack of bearing.

3. SIMPLIFIED EQUIVALENT LINEAR SP-F MODEL

Investigating the nominal load of electromechanical piezoelectric transducers (PPE-M), one can represent the piezoelectric reverse wave engine with three-phase resonator on the equivalent electric diagram in simplified form – only primary windings – as three identical four-poles frictionally coupled by resistance R_F expressing frictional action resistance (Fig.3).

Presented linear approximation of equivalent SP-F model, allow to draw kinematic and dynamic interdependencies between separate engine elements and energy conversion schema. Transformer T_F is characterized by ideal frictional coupling between oscillator and rotor or runner with transformation coefficient N_F equal to:

$$N_F = \frac{M}{F} \quad \text{or} \quad \frac{F_b}{F}$$

SP-F output power:

$$P_N = \omega_N \ M_N \ \text{or} \ F_b \ v_b$$

SP-F/L nominal power one can find out of mechanical diagram in linear approximation by slip s = 0.5 (Fig.4).

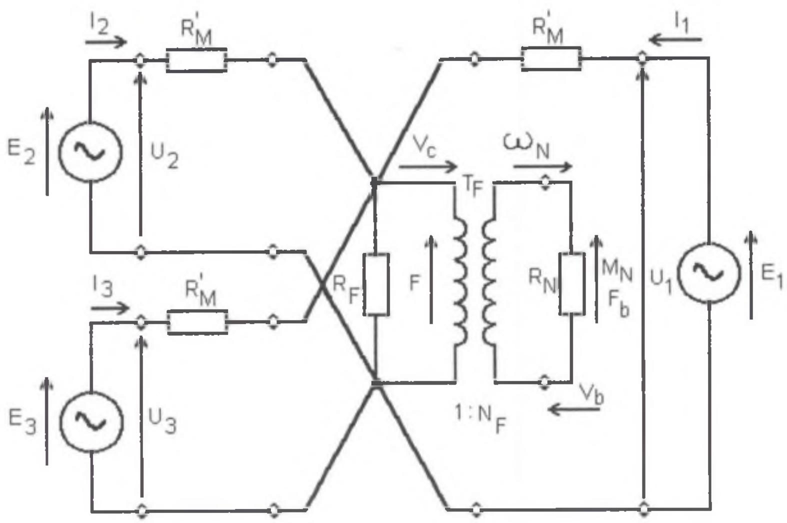

Fig.3. Simplified equivalent PPE-M/F schema

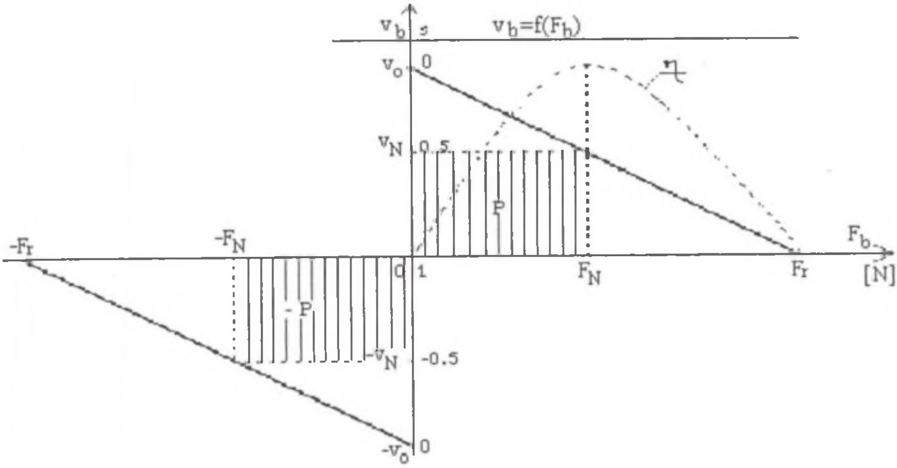

Fig.4. Mechanical diagram of SP-F/L

4. SP-F/L SUPPLYING AND CONTROLLING

SP-F/L supply schema enable generation of three electric signals with phase offset equal e.g. 120^0 between each other, Fig.5.

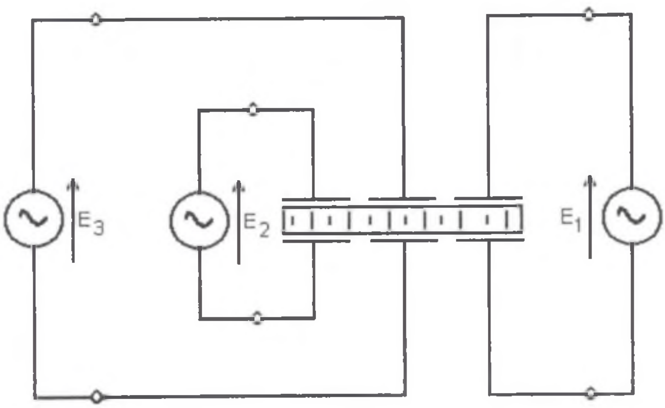

Fig.5. SP-F/L supply circuit with independent one-phase inverters

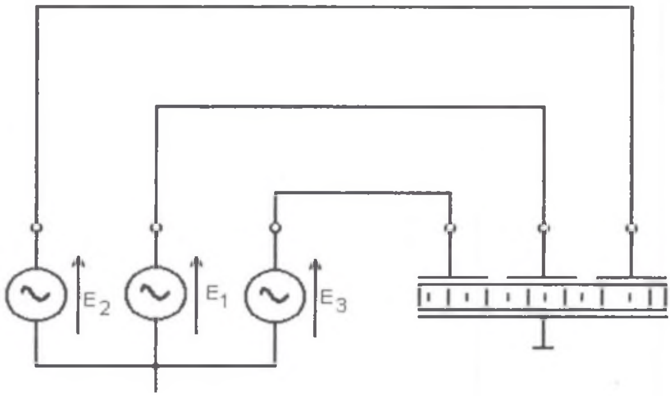

Fig.6. SP-F/L supply circuit utilizing three-phase generator

The inverter contains control box based on 8-bit microcontroller. It is used to control keyboard, display and phase locked loop PLL. Multiturn potentiometer sets the output frequency, whereby one can align it quite precisely to current oscillator resonant frequency. Measuring of inverter supply current makes possible to monitor its values and, indirectly, to correct oscillator resonant frequency. It was assumed, that this frequency is unstable because of, e.g., temperature. Presented circuit shows stable enough frequency, so correction is needles. Use of phase locked loop, synchronized by reference frequency from microprocessor circuit, makes possible setting of any output frequency (in the 20 – 200 kHz range), characterized by good stability in time.

Numeric keyboard and alfanumeric display help in setting of working parameters, like time of work for rotating left or for movement of runner in the left direction, time of work for reverse movement, time of stop, count of cycles. One can select one of pre-programmed, ready to use work algorithms.

Three-phase inverter supplies the linear piezoelectric engine model with alternating voltage having resonant frequency F_0, Fig.6.

The simplest way of building a three-phase voltage source is suitable connection (e.g. "star") of three one-phase sources with output voltage phases offset by $2\pi/3$, Fig. 6. For load, the inverter is alternating voltage source. Three-phase inverter one can build connecting three one-phase inverters with output voltage phases offset by 120 degrees. In effect there are complicated primary circuits, so this is not too popular way of design. Usually three-phase inverter contains three groups of valves supplied by single source of direct voltage and controlled so, that valve groups output voltages are offset by 120 degrees.

Inverter output voltage amplitude control is obtained by inverter supply voltage amplitude changing or by adequate output voltage modulation. Output voltage modulation in the presented inverter is made by input voltage changing. The mains voltage has been transformed to 12 V. After rectifying and stabilizing it is direct to increasing transformer which outputs adjusted voltage in the range of 0 to 100V. By implementation of the circuit there were problems with selection of power transistor controlling buffers and selection of appropriate transistors. For frequency near 200kHz the power losses of transistors, working in two-state regime, were quite high, so there was need for better cooling. Death time – time delay between complementary transistors turning on – proved to be critical parameter.

Manufacturing and initiating of inverter with frequency higher then 100 kHz is quite laborious and need accuracy in assembling. Power transistor control timing and high voltages may be unfavourable for electronic circuit working. It would be well to make the electronic circuit more compact (integrate) for energy-electronic applications to make it more proof against EMI.

5. SUMMARY

The successive finishing of scientific works on the development of the piezoelectric engines with three-phase wave resonator is significant step to rising of new generation of electric reverse engine and also piezoelectric linear engine SP-F/L, what is important for evolution of piezomechatronics, biocybernetics and automatization and robotization of elementary "micro" and in the future nanotechnology with digital control in automated manufacturing systems (APS).

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