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COMPUTER SIMULATION OF A PLANAR AEROSTATIC TWO-COORDINATE RELATIVE BASE WITH ELECTROMAGNETIC DRIVE

SUMMARY

The paper describes the construction and the principle of operation of a planar aerostatic two-coordinate relative base with electromagnetic drive. Stages and results of the computer simulation of the planar aerostatic two-coordinate base are presented.

Keywords: *aerostatic relative base, distribution of pressure*

BADANIA SYMULACYJNE PŁASKIEJ AEROSTATYCZNEJ PODPORY WSPÓŁRZĘDNOŚCIOWEJ Z NAPĘDEM ELEKTROMAGNETYCZNYM

W artykule omówiono budowę i zasadę działania płaskiej aerostatycznej podpory współrzędnościowej z napędem elektromagnetycznym. Opisano etapy symulacji komputerowej płaskiej aerostatycznej podpory współrzędnościowej. Podano wyniki badań symulacyjnych.

Słowa kluczowe: *podpora aerostatyczna, rozkład ciśnienia*

1. INTRODUCTION

The relative base – air-gap – absolute base system (planar stepping motor) is the main element of the precise coordinate positioning systems of the specialized devices. Possible fields of application of the precise coordinate systems with the planar stepping motor [4, 7]: manipulators, machine tools, measuring machines, assembly operations in microelectronics and instrument engineering, surface mounting elements and units assembly, laser technological complexes.

The basic direction of the development of the structure of the aerostatic relative bases with electromagnetic drive is to look for the solutions characterized by the higher stiffness. The stiffness determines a capacity of the relative base to counteract the working load (payload). The action of the payloads causes a change of the height of the air layer h (air-gap) between the absolute base and the relative base.

The determination of the range of the value of the air-gap h, for which the stiffness is constant and maximum, requires working out of the particular model of the system [1] and computer simulation.

The computer simulation results enable the choice of the required alternative structure of the aerostatic relative bases with electromagnetic drive in particular devices.

The planar aerostatic two-coordinate relative base is a tribology system, described by the equations resulting from the following laws:
- the law of conservation of momentum (the Navier–Stokes – equation of motion),
- the law of conservation of mass (equation of continuity),
- the law of conservation of energy.

In modelling of the aerostatic lubrication systems we consider, in various degree, equations describing the air properties. Suited to the needs and computational possibilities, specific models are described by a smaller or larger number of assumptions and simplifications.

The basic assumptions in the aerostatic lubrication theory are as follows:
- there is no change of pressure p in the direction perpendicular to the working surfaces,
- air flow through the air-gap is laminar and continuous,
- viscosity of the air is constant in the whole area of the sliding layer,
- the working surfaces are undistortable,
- there is no cavitations,
- the influence of the inertial forces of the air on work parameters of the system is negligible,
- ambient interaction is constant (constant temperature and pressure).

2. OBJECT OF RESEARCH

Figure 1 shows basic elements of the relative base – air-gap – absolute base system:
1) planar aerostatic two-coordinate relative base – the forcer with gas-film lubrication (aerostatic lubrication);
2) absolute base – the immovable stator (platen);
3) motion control card;
4) air filter and regulator.

Table 1 shows the common technical data of the planar stepping motor.

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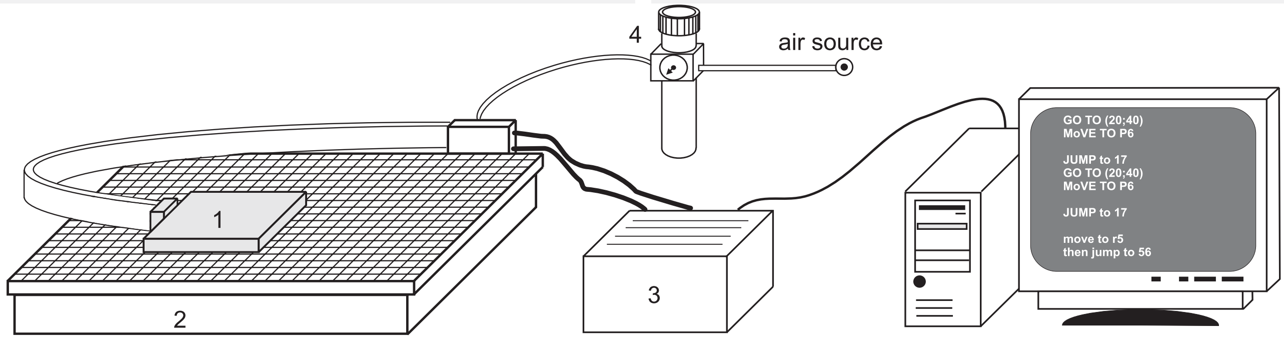

Fig. 1. Basic elements of the relative base – air-gap – absolute base system
1–4 see text

Table 1
Common technical data of the planar stepping motor [7]

Characteristics, measurement units	Data
Forcer type	Hybrid stepping motor
Forcer/Stator thread period, mm	0.64; 1.00
Number of phases	2
Rated current/ phase, A	3±0.3
Peak current/phase, A	6
Max. speed, m/s	1.5
Repeatability accuracy, mm·10^{-3}	3
Positioning accuracy, mm·10^{-3}	±15*
Resolution, mm·10^{-3}	1.0
Air supply pressure, MPa	0.32 ±0.01
Air-gap during operation, mm·10^{-3}	8–12
Air quality	1 micron fine filter, oil-free, dried
Ambient temperature operational band allowed	20°C±15

* depend from forcer model

The planar aerostatic two-coordinates relative base consists of the following elements:
– aluminium frame,
– electromagnetic modules: I, II,
– pneumatic system.

The principal element of the pneumatic system is a built-in pneumatic system with nozzles and bearing chambers providing an air into the air-gap between the absolute base and relative base. The sliding surfaces of the immovable absolute base and the moving relative base in the Cartesian co-ordinate system are completely separated by supply of compressed air into the gap between the working surfaces. In this manner a thin air layer, which pressure is greater than atmospheric pressure, is created. This is an air cushion, which produces aerodynamic lift indispensable to free movement of the relative base over the immovable absolute base.

The working surface of the relative base (Fig. 2) contains two groups of orthogonal electromagnetic modules. The electromagnetic modules (I) are responsible for movement of the relative base along X-axis, and modules (II) are responsible for movement of the relative base along Y-axis.

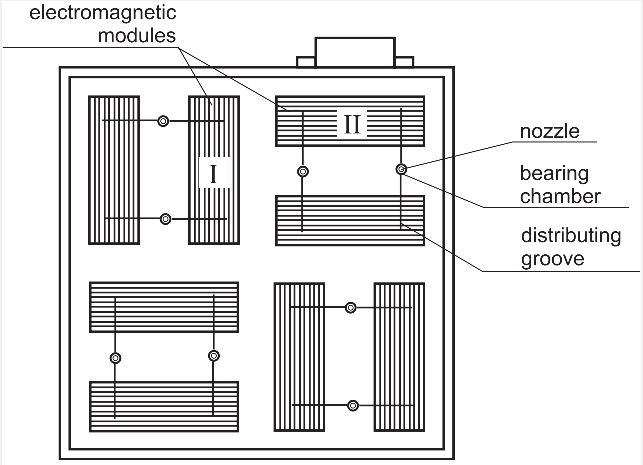

Fig. 2. The working surface of the relative base

The planar stepping motor converts control pulse signals directly into a sequence of linear shifts. The direction of shifts made by the forcer is related to the sequence of passing impulses and the forcer's speed depends on frequency of the current. The value of the shift of the forcer in regard to the stator depends on current pulses. The operation of the planar stepping motor is not possible without an appropriate control system. The control system ensures the desirable performance of the step motor [4].

Figure 3 shows elementary electromagnetic modules: 3a and c – two-phase modules, 3b and d – modules consisting of two single-phase modules. The electromagnetic module consists of two magnetic cores and the permanent magnet, which is sandwiched between the cores (Fig. 3a, b). The magnetic cores are joined by means of a yoke (Fig. 3c, d) [5]. The winding is wound on each core. The working surface of electromagnetic modules has a spaced toothed structure with a definite phase shift from pole to pole.

Figure 4 shows characteristic geometrical quantities and forces of the relative base – air-gap – absolute base system.

The air cushion acting as an air layer, whose pressure is greater than atmospheric pressure, produces aerodynamic lift F_n. By means of the aerodynamic lift the relative base is suspended at height h above the absolute base. The use of the air-gap completely eliminates the physical contact of the working surfaces, and the application of the aerostatic lubrication reduces friction and wear of the sliding surfaces.

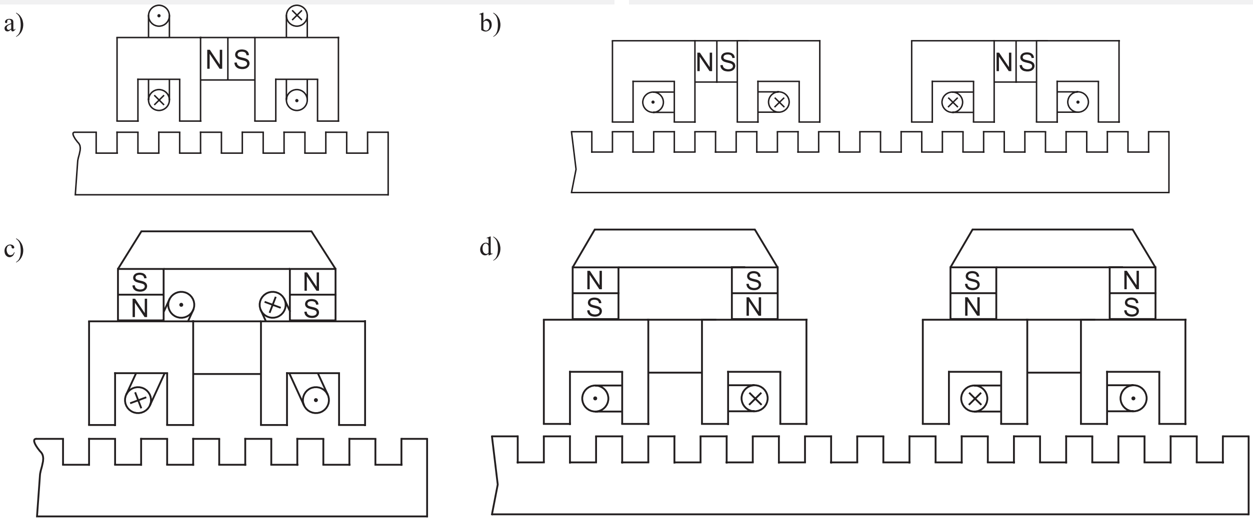

Fig. 3. Cross sections of the elementary electromagnetic modules
a)–d) see text

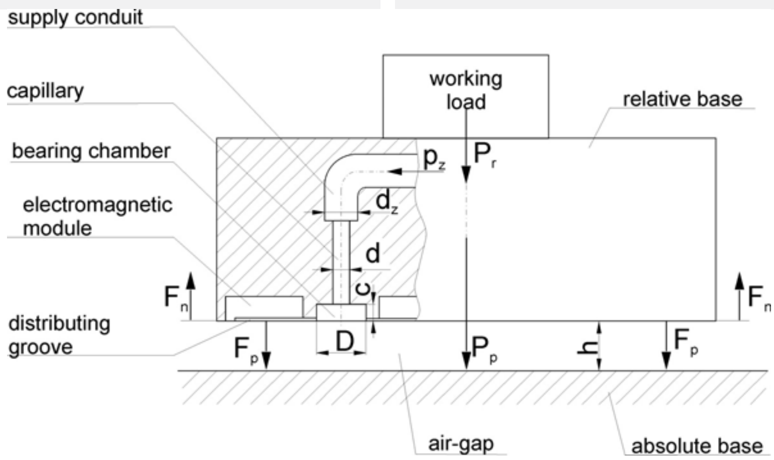

Fig. 4. Characteristic geometrical quantities and forces of the relative base – air-gap – absolute base system

The aerodynamic lift F_n (reactive force of air cushion) counterbalances the loads resulting from gravity (weight of the relative base P_p plus weight of the object mounted on relative base – payload P_r) and magnetic attraction forces F_p. The attraction force of the relative base towards the ferromagnetic absolute base is caused by the permanent magnets, which are part of the electromagnetic modules.

3. COMPUTER SIMULATION

Figure 5 shows stages of a computer simulation of the planar aerostatic two-coordinate base with electromagnetic drive:

– Calculation connected with airflow in the relative base – air-gap – absolute base system:
  • calculation of the values of the discrete pressures p in the air-gap and resulting from those distributions the values of the aerodynamic lift F_n,
  • calculation of the stiffness of the system $j = \frac{dF_n}{dh}$,
  • calculation of the working point h_r.

– Determination (based on the equilibrium of forces) of the number of the elementary electromagnetic driving modules n_e, and optimal distribution of the electromagnetic modules on the working surface of the relative base.

For the computer simulation of the planar aerostatic two-coordinate relative base with electromagnetic drive we worked out a computer program SPAP.

The computer program SPAP will be used for computer aided design (design of a structure) of the planar aerostatic two-coordinate relative base with electromagnetic drive.

Computer program SPAP consists of two modules:

1) SPAP^{AERO} – used for calculations connected with airflow in the relative base – air-gap – absolute base system [3],
2) SPAP^{MAG} – used for calculations connected with flow of magnetic flux in the electromagnetic drive.

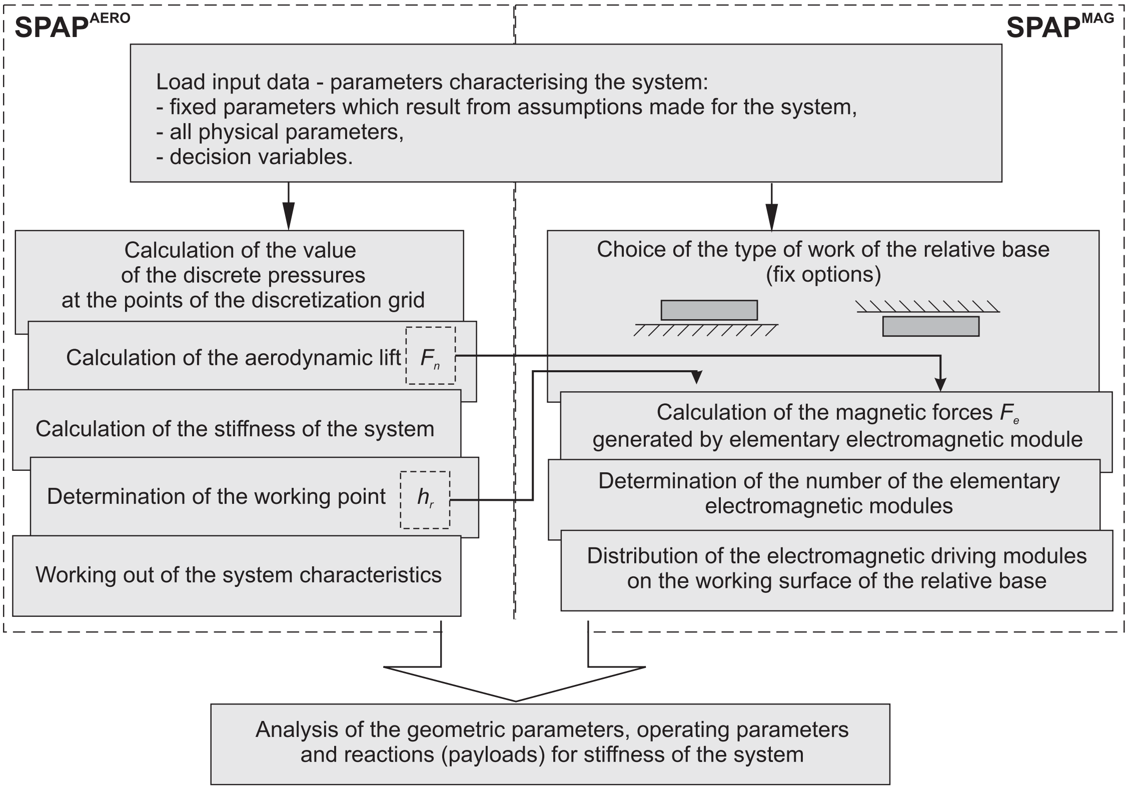

Fig. 5. Stages of the computer simulation of the planar aerostatic base

The computer program SPAP should fulfil the following assumptions:

1. Inputs should determine unambiguously structural parameters of the relative base – air-gap – absolute base system (decision variables):
   – dimensions of the working surface of the relative base,
   – dimensions characterising the nozzles, the bearing chambers and distributing groove,
   – the number of the nozzles,
   – dimensions characterising the electromagnetic drives,
   – weight of the relative base and weight of the object mounted on relative base (payload).
2. The choice of the type of work of the relative base (above absolute base, upside down).
3. Computer program should enable:
   – calculation of the values of the discrete pressures p at the points of the discretization grid,
   – calculation of the aerodynamic lift F_n,
   – estimate the aerodynamic lift versus the height of the air-gap ($F_n = f(h)$),
   – calculation of the stiffness of the system $j = \frac{dF_n}{dh}$,
   – determination of the number of the elementary electromagnetic driving modules and optimal distribution of the electromagnetic modules on the working surface of the relative base [6].
4. Result of calculations should be shown on the computer screen and possible to print.

4. COMPUTER SIMULATION RESULTS

Figure 6 shows 3D diagrams that were obtained as a result of the computer simulation in the computer program SPAP^{AERO}. Figure 6a shows 3D diagram of pressure p in the air-gap and resulting from this distribution the value of the aerodynamic lift F_n. This diagram was obtained for the working surface of the relative base shown in the Figure 6b. Computer simulation results were obtained for the following input data:

– step of the grid: $\Delta x = \Delta y = 5$ mm;
– integers fixing step of the grid: $m = n = 16$;
  $l_x = l_y = 80$ mm; $h = 15$ μm;
– coefficient of discharge: $\xi = 0.7$;
– pressure supply $p_z = 0.55$ MPa.

Figure 6c shows 3D diagram of pressure p in the air-gap and resulting from this distribution the value of the aerodynamic lift F_n. This diagram was obtained for the working surface of the relative base shown in the Figure 6d. Computer simulation results were obtained for the following input data:

– step of the grid: $\Delta x = \Delta y = 2.5$ mm;
– integers fixing step of the grid: $m = n = 32$;
  $l_x = l_y = 80$ mm, $h = 15$ μm;
– coefficient of discharge: $\xi = 0.7$;
– pressure supply $p_z = 0.55$ MPa.

We can see, that appropriate distribution of the eight nozzles on the working surface (Fig. 6a) leads to considerably greater value of the aerodynamic lift F_n than in case of the working surface with four nozzles (Fig. 6c).

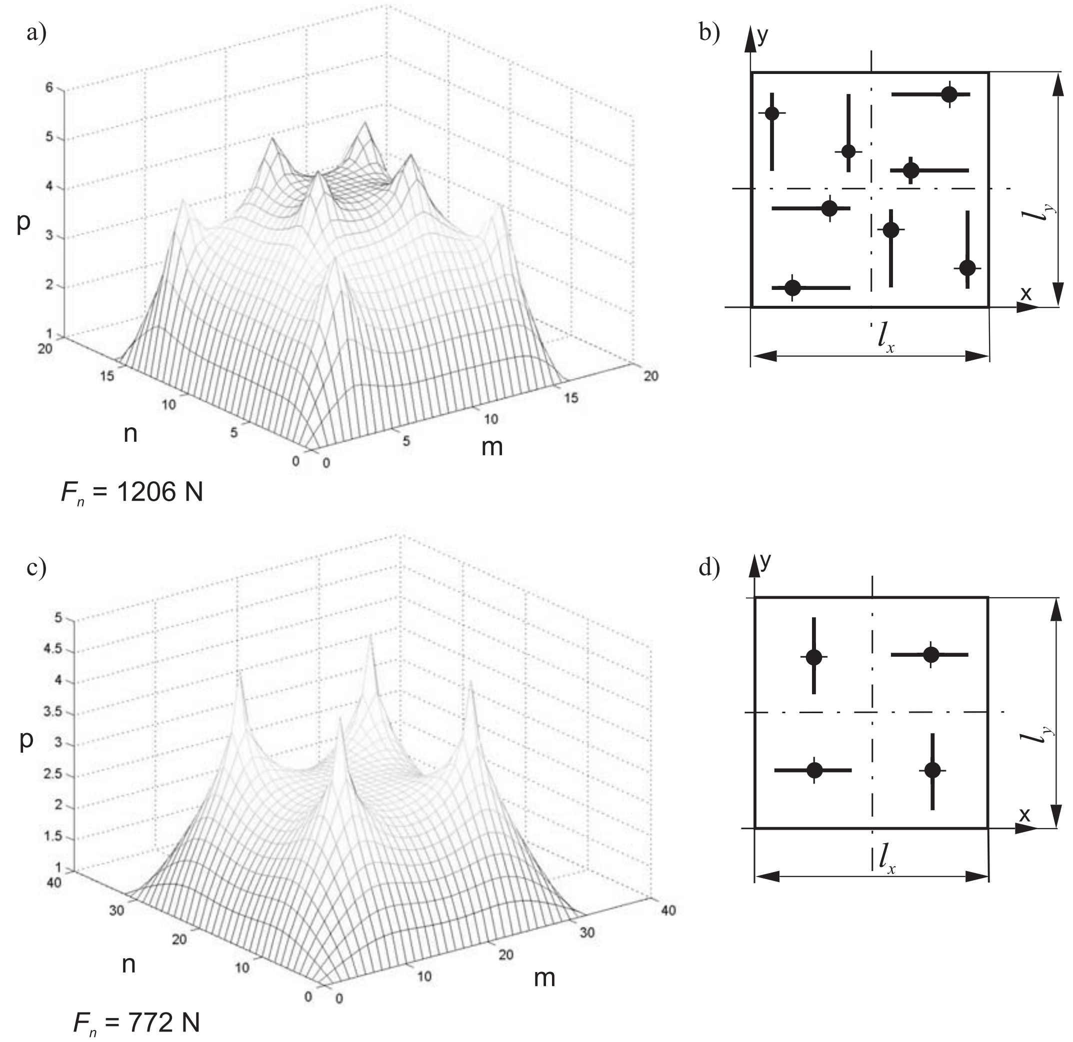

Fig. 6. Distribution of the air pressure p in the relative base – air-gap – absolute base system
a)–d) see text

The values of the discrete pressures p and resulting from their distribution the aerodynamic lift F_n are calculated for different values of the air-gap h. This way we can estimate the aerodynamic lift versus the height of the air-gap ($F_n = f(h)$). This dependence enables us to calculate of the stiffness of the system.

5. CONCLUSIONS

The correct computer program for simulation of the system accelerates the design process of a structure of the planar aerostatic two-coordinate relative base with electromagnetic drive. The proper choice of the specific decision variables leads to the required structure of the aerostatic relative bases with electromagnetic drive. During the design process of the precise coordinate positioning systems of the specialized devices with the aerostatic relative base, it is often necessary to preliminary estimate the different alternative structures and to determine the desired operating characteristics of the system.

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