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Drive systems of magnetic disks as mechatronic systems - overview of research issues and perspectives for further development

***Abstract**. In the article relationship between permanent increase of areal data density in magnetic recording and construction of drive system for reading and writing heads is shown. The growth of areal data density in period of last 16 years is considered and highlighted in the context of the internal structure development of media disks as well as construction of head positioning system. Finally, authors show advantages of new structure of drive system of head positioning system with increased number of degrees of freedom.*

***Streszczenie.** W artykule przedstawiono związki pomiędzy budową systemu pozycjonowania głowic a wzrostem gęstości powierzchniowych danych pamięci masowych. Wzrost gęstości powierzchniowych danych został przedstawiony w kontekście struktury wewnętrznej nośników danych oraz budowy systemu pozycjonowania, na przestrzeni ostatnich 16 lat. Przedstawiono również strukturę systemu pozycjonowania o wielu stopniach swobody, jej zalety, które mogą się przyczynić do dalszego wzrostu gęstości powierzchniowych danych. (**Systemy napędowe dysków magnetycznych, jako systemy mechatroniczne - przegląd problemów badawczych i perspektywy dalszego rozwoju**).*

Keywords: data areal density, mass storage, magnetic disk, head positioning system.
Słowa kluczowe: gęstości powierzchniowe danych, pamięci masowe, dyski magnetyczne, systemy pozycjonowania głowic.

Growth of data areal density

The data areal density is fundamental parameter of hard disk drive which defines the amount of information written on unit area of a rotating magnetic disk. Areal density can be calculated as product of two parameters: data track density and bit density. The growth of areal density over last 16 years is presented in Fig.1.

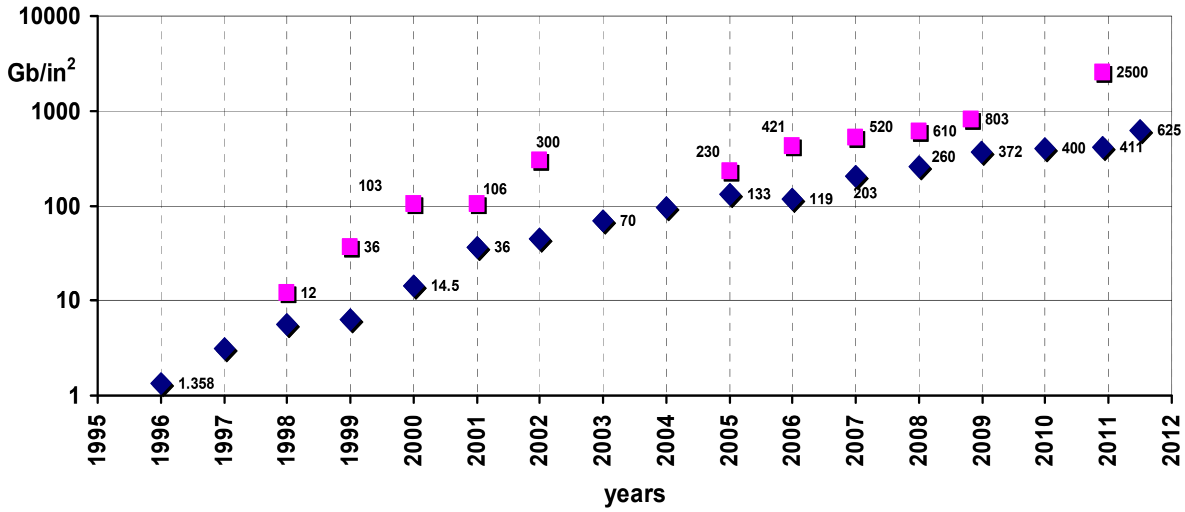

Fig.1. The data areal density growth over last 16 years (the set of data on the left hand - denoted by squares - are connected with longitudinal recording method; the set of data on the right hand - denoted by squares - are connected with perpendicular method of magnetic recording; the data denoted by rhombus are connected with data areal densities uses in commercial product)

The first hard disk drive which overcame the limit of 1 Gb/in^2 data areal density was IBM Legato (it happened in 1996). Right now the highest areal densities are used in Western Digital 2TB Black hard disk drive (400 Gb/in^2) and Seagate GoFlex Desk (615 Gb/in^2). Reaching such incredible values of areal density was possible by means of many constructional and technological changes in different areas of modern hard disk drive related to structure of magnetic media disk [1-4], as well as, to construction of: reading and writing heads [6], spindle system (main drive of data disk) and, finally, positioning drive system [9, 10, 15]. In period of years 1996 to 2002 the most promising technology of magnetic writing was longitudinal way of writing [1]. But in a few years it occurs that the magnetic media consisting only with one layer of magnetic material is not sufficient and do not allow to decrease the bit cell size (volume). Modification of typical media by adding supplementary magnet under layer increases the thermal stability of media disk and allows reaching (in laboratory environment) data areal density equal to 300 Gb/in^2. Such a modified magnetic disk media is known as AFC (antiferromagnetically - coupled media) or "pixie dust" media. Progress in longitudinal recording technology and AFC media during years 1998 to 2002 is presented in Fig. 1 on the left hand. The most promising technology started in year 2000 when the Hitachi Company presented the first perpendicular recording media (PMR) and showed that perpendicular recording may be very good alternative for magnetic high density drives. The company elaborated and presented in 2005 the perpendicular magnetic recording media which has allowed writing information with 230 Gb/in^2 areal density. This perpendicular magnetic recording (PMR) media has been in use up-to-now and some modification of this technology occurs as the so-called granular-type perpendicular magnetic recording media [1, 3]. Another possibility for reaching high areal densities is connected with the patterned media (BPM) [1, 2, 4]. The patterned media consists of the islands which are lithographically patterned into regular arrays. Every island defines one single bit.

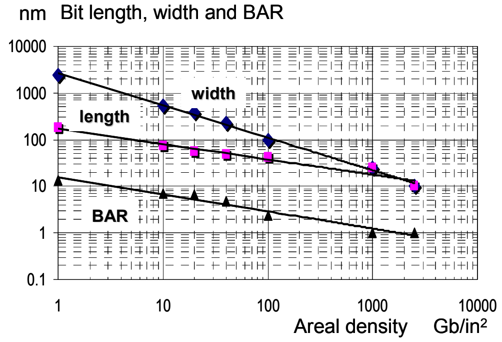

Fig. 2. Decrease of bit width, length and BAR (bit aspect ratio) v. areal density growth in period of last 16 years

In Fig.2 the drop in the dimension of bit length and width v. data areal density increase is presented. It is worth underlining that in 1996 (when the areal density reaches 1 Gb/in2) the width of magnetic track was near 3 μm and the most advanced media disk used "round" bit with diameter about 10 nm [4]. Such small dimensions of data track, as well as, track pitch pose a challenge for head positioning system and its drive system.

Possible writing technology and media disk technology are put together in Table 1. The most promising disk media technology seems to be the patterned media technology which leads to changes in head writing technology and can result in the so-called "wrapped-around-shield" (WAS) head [6].

Table 1. Specification of writing technology and used disk media technology

	Writing technology	
	Longitudinal	Perpendicular
Disk media technology	AFC media [1]	ECC media [13]
		Granular Perpendicular media
	SF media [5]	BPM media [2]

Head positioning system components

The construction of head positioning system depends remarkably on data areal density. For a simple system with low requirements for values of areal densities it is enough to have only one source of driving torque for head positioning system. The driving torque is produced by a VCM motor. This kind of a motor (D.C. motor excited by a permanent magnet, with the limited range of angular motion) is still used in a modern head positioning system. Proper design of the driving system for head positioning system should take into account some additional phenomena: repeatable runout (RRO) and non-repeatable runout (NRRO). Repeatable runout (RRO) and non-repeatable runout (NRRO) describe levels of vibration (generated by a rotating spindle system) and their maximum amplitudes which cannot exceed the length of the track pitch. The schema describing internal components of a driving system for a modern head positioning system is presented in Fig.3.

It was noticed very early that one VCM motor will not be sufficient to follow thin track of a hard disk which gradually, from year to year, becomes narrower. For solving this problem many proposals were considered and general conclusion was that there is need for adding new auxiliary motors. The modern solution of the driving system for a head positioning system is presented in Fig.3 and takes this concept widely into account. As can be seen, a driving system consists not only of a VCM motor (main source of driving torque) but also auxiliary ones of different types.

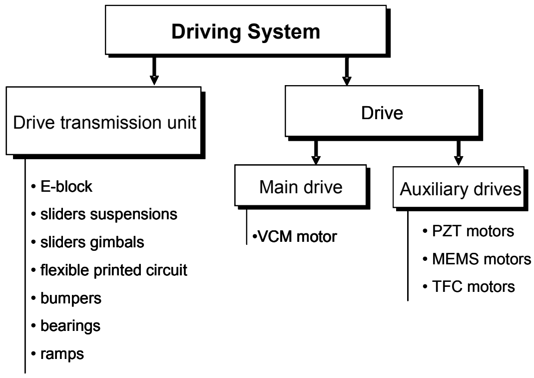

Fig. 3. Schema describing driving system for head positioning system as mechatronic system

In late 90's of last century very popular conception of auxiliary drives was associated with MEMS micromotors. The applied micromotors are designed, either for direct drive of a slider, or for direct drive of heads.

The constructional solution for direct drive of the slider (achieved with the help of a MEMS micromotor) is presented in Fig. 4. Outer diameter of this micromotor

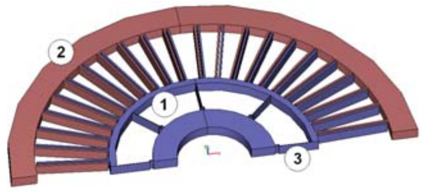

Fig. 4. Simplified geometry of rotary MEMS micromotors (one half) for direct drive of the slider. (1) – stator, (2) – rotor, (3) – flexure [9]

reaches 2.6 mm and the height equals 100 μm. Appling the voltage +/- 40 V at stator terminals it is possible to obtain displacement of head in range of +/- 1.74 μm [7] (the resonant frequency equals 1.7 kHz).

The MEMS micromotor for direct drive of heads is presented [8] in Fig. 5. In [8] there are given very detailed information about construction, manufacturing and a mathematical model of this linear motor. The designed micromotor has dimensions: 300 × 1000 × 20 μm. The linear displacement of heads, at 30 V supply, is equal to 1.47 μm. With the use of this construction the servo bandwidth of a head positioning system increases to 2.27 kHz.

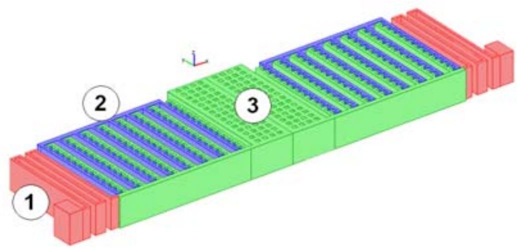

Fig. 5. Simplified geometry (one half) of linear MEMS micromotor for head positioning system. (1) – supporting springs, (2) – stator, (3) – mover (its central part is intended for head mounting)

At the beginning of this century the idea of auxiliary direct drive for a slider suspension with PZT motors was presented. The original design was presented by the Fujitsu and Hutchinson Technology Company. The fundamental advantages of the PZT micromotors (directly driving slider suspension) are evident: not complicated manufacturing process and easy assembly. In order to push this solution into market, it was necessary to overcome some problems related to PZT material fixation (connection among metal parts of E-block and a suspension), which were solved with the help of gluing [10]. Western Digital Company employs this solution for its hard disk drives WD 2TB Black.

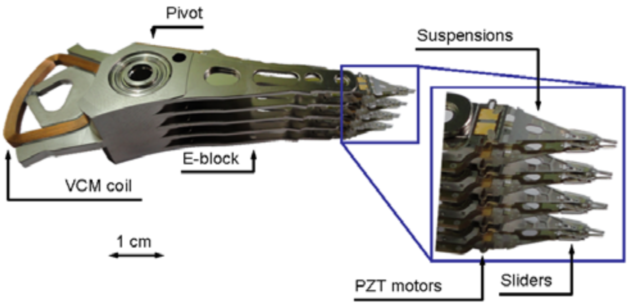

Fig. 6. Modern head positioning system taken from WD 2TB hard disk drive

The PZT micromotors applied in a head positioning system are presented in Fig. 6. As seen, a driving system consists of a VCM motor (as a main source of a driving torque) and eight PZT motors (auxiliary motors for direct drive at slider suspension). Approach similar to this used in a WD 2TB was proposed in [10], but in opposite to the WD 2TB, the suspension was driven by two separate PZT stripes (the PZT stripes actuated suspension is presented in Fig. 7.

Another problem arising in hard disk drive technology is to stabilize the flight height of a slider on the desired level which assures proper value of “signal to noise ratio SNR” of read back signals from magnetoresistive heads. “Signal to noise ratio SNR“ can be estimated with the help of the following equation [1]:

$$SNR \approx \frac{0.31 PW_{50} BW_{read}}{a^2 D(1+\sigma^2)} \approx \frac{B^2 W_{read}}{\alpha^2 D^3 (1+\sigma^2)} \quad (1)$$

where B – bit length, W_{read} – read width of the head, PW_{50} – pulse width at 50% of signal magnitude, a – transition gape (gape between bits), D – magnetic grain diameter, σ – normalized grain size distribution, $\alpha = a/D$.

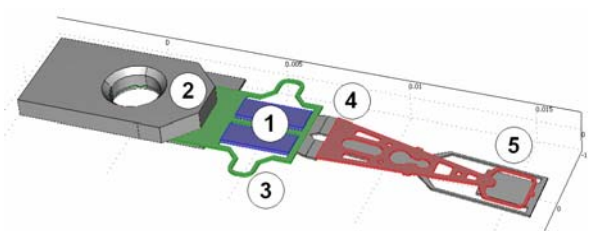

Fig. 7. PZT stripes - actuated suspension. (1) – PZT stripes, (2) – one ends of E-block, (3) – so-called Φ shaped hinge, (4) – suspension, (5) – slider

In a modern hard disk drive keeping value of SNR ratio at given level results in proper flight height control (should be kept at the level between 5 – 10 nm [11, 12] or even less) and, of course, is connected also with magnetic media quality [1-4]. It is worth mentioning that actually some promising research projects are developed and because of them the flight height of slider can be decreased to 3 nm (!). There is two main ways for stabilizing the control system responsible for the flight height of the slider:

- shaping bottom face of a slider, as well as, forming air bearing and loading beam (part of suspension between parts (4) and (5) in Fig.7). It leads to keeping in balance force generated by the air bearing and force from the load beam generated by the suspension,
- active control of head flight height by means of auxiliary MEMS micromotors or utilizing thermal expansion (thermal flight high control - TFC) of head parts (this last method is quite new [11, 12] and allows to obtain protrusion of heads to disk surface up to 4 nm at medium flight height 8 nm).

New concepts for modelling head positioning system with high areal densities

Mathematical modelling of a head positioning system is usually performed by means of transfer functions. This way for the mathematical modelling of a head positioning system is used in [7, 8, 15]. As has been mentioned before, achieving high areal densities requires the additional micromotors in the kinematic chain of a head positioning system. In general, it is very difficult to formulate a mathematical model which takes into consideration both the structure of a kinematic chain and auxiliary micromotors. In [9] there is shown promising methodology for mathematical modelling of a head positioning system adopting mathematical methods used in robot manipulators modelling. The head positioning system is regarded as special case of the branched kinematic chains which consist of a bough and branches having different numbers of degrees of freedom. Assuming that a head positioning system cooperates with two magnetic disks (see Fig.8), the head positioning system can be represented by the kinematic chain represented by a bough and four branches. Analyzing the new achievements in constructions of a head positioning system (presented in chapter 1 and 2), as well as, taking into account some trends related to future development of magnetic disk, it is expected that head positioning systems allow in the nearest future:

- to attenuate the vibrations coming from spinning and rotated spindle system [14],
- to attenuate the influence of structural vibration of kinematic chain on head position [15],
- to attenuate the vibrations acting in perpendicular direction to magnetic disk surface [16],
- to compensate the so-called skew heads [17],
- to allow to control flight height of slider or heads [11, 12].

Above - mentioned purposes can be achieved by means of a head positioning system with the branched kinematic chain presented in Fig. 8 [9], [19 - 21].

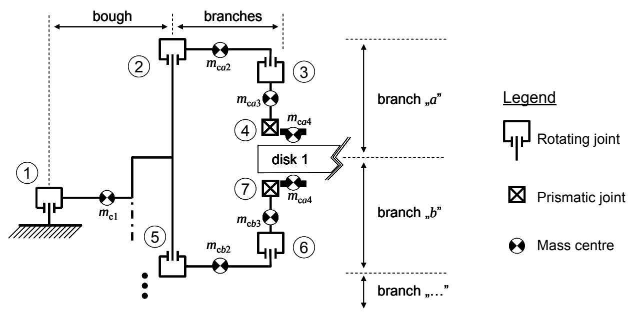

Fig. 8. Branched kinematic chain for head positioning system cooperating with high data areal densities

Such a system has many important advantages. In the rotating joint - denoted in Fig.8 by (1) - main torque is generated by VCM motor (this is fundamental source of driving torque to a whole positioning system). In the rotating joints - denoted in Fig.8 by (2) and (5) - auxiliary PZT motors enable to attenuate of structural vibration (see [10]). In the joint - denoted by (3) and (6) - additional torque generated by MEMS micromotors allows to compensate head skew [17] and, finally, thermal micromotors TFC - denoted in Fig.8 by (4) and (7) - can be helpful in heads flight height control [11, 12, 16].

Conclusions

Mass storage devices (hard disk drives) belong to the sets of devices which have been developing in incredible dynamic way and which influence considerably upon our daily life. General and systematic progress in magnetic media technology, heads technology, drives of head positioning system technology enables us to state that capacity of these devices will be continuously increased and that manufacturing cost will be systematically decreased. It is expected that in near future the areal density will reach 4-5 Tb/in^2 [18]. It seems that it will be achieved with the help of the patterned media technology. Another interesting and promising trend in a storage technology is combination of SSD (Solid State Drive) technology with the HDD technology, which may result in very attractive hybrid drives offering both: high capacity and fast access to the data. This hybrid disk technology (Solid State Hybrid) is proposed by Seagate Corporation.

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