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Coefficients of the Evolution Potentials of the Informative Features – Linear, Track and Areal Density of Recording on Storage Devices on Magnetic Hard Disks*

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Abstract: *The present paper analyzes the problems appearing in the determination of the limit maximal values of the informative features. An approach is proposed to compute the coefficients of the evolution potential of the informative features – Linear Density (LD), Radial (track) Density (RD) and Areal Density (AD) of recording on storage devices on magnetic hard disks.*

Keywords*: coefficients of the evolution potential, informative features, linear density, radial (track) density, areal density, HDD.*

Introduction

The investigations of the main characteristics of the informative features – quantity and relevance of the information, have shown that it is not possible to apply them in the evaluation of the potential reserves for improvement of the objects they describe. The solution of this problem has imposed the introduction of a new criterion for the informative features, called by the authors evolution potential. The ratio of the boundary numerical values (theoretical and expert estimated) of the corresponding informative features to the values, achieved under industrial and/or laboratory conditions, was called coefficient of the evolution potential.

The numerical value of this coefficient for the main informative features of the Magnetic Information Carriers (MIC) – Linear Density (LD), Radial (track) Density (RD) and Areal Density (AD) enable the obtaining of sufficiently convincing evaluation of the potential possibility for their raising [1].

In reference [2], sets and subsets of informative features are formed, that describe the information carriers and the storage devices on magnetic hard disks

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(SDMHD). Unfortunately, after 2001 the leading companies-producers do not reveal the digital values of LD and RD (TD), but only that of AD. This makes more difficult the expert evaluation of LD and RD densities obtained, and hence, the possibilities for their improvement.

The purpose of the present paper is to analyze the problems appearing in the determination of the limit maximal values of the informative features and to develop an approach for computing the evolution potential coefficients.

Analysis of the problems appearing in the determination of the limit maximal values of the informative features

The magnetic record is known since the end of XIX-th century [3], but only in the second half of the XX-th century it gained remarkable dynamic growth [4]. Its physical essence is directed magnetizing of magnetic coatings. Until 90-ies of the last century, the most wide-spread coatings were on varnish basis – powdered magnetic materials dispersed in a polymer matrix. The purpose of the technology was to use powdered magnetic materials from single domain particles and the magnetizing of each particle. The smaller the single domain particles are the higher recording density is achieved.

Towards 1990 the achievements were – single domain magnetic particles with average dimensions of 0.05μm (0.04-0.06) μm or maximal LD of record 500 000 bits per inch (bpin). According to the theory of the magnetic record, the same density will appear in radial direction also – 500 000 tracks per inch (tpin). Due to the fact that RD is influenced by a number of constraints imposed by the positioning system and the method of the magnetized record, RD (TD) of recording is always considerably smaller than LD. The product of the two densities (LD and RD) gives the recording density on one square inch.

(1) $$\text{LD (bpin)} \times \text{RD (tpin)} = \text{AD (bpin}^2\text{)}.$$

During 90-ies of the last century, the thin-layer coverings have replaced the coatings on varnish basis, because they enabled the obtaining of single domain magnetic particles with dimensions 0.021 μm. This allows recording LD of 1.25×10^6 bpin.

The maximal limit values of the record densities depend on the size of the particles, which allows the recording of at least one bit of information on every one of them. The last announces of the leading companies (IBM, Jujitsu, Toshiba, etc.) inform of recording also in the area of superparamagnetic dimensions of the particles.

Fig. 1 gives the relation of the magnetic performance and the size of isolated (not interacting magnetically) Nickel particles in galvanic coating at 300 K [3, 4].

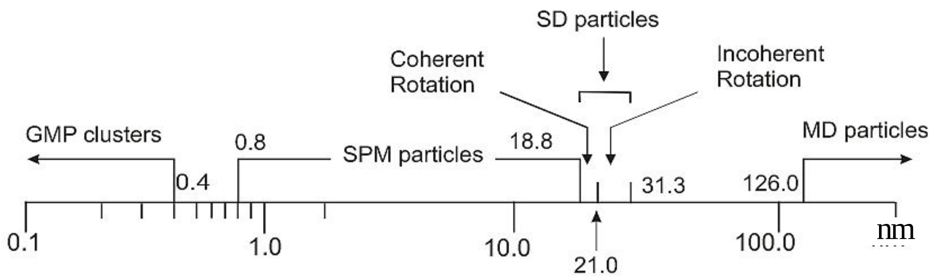

Fig.1. Relation of the magnetic performance and the size of isolated Nickel particles in galvanic coating at 300 K

The region of the particles, called clusters is placed under 0.4 nm. They are constructed from a group of atoms and have an enormous magnetic moment [5]. The magnetic moment of these clusters is equal to the sum of the magnetic moments of the atoms which form them. The particles with dimensions from 0.7–0.8 up to 18.8 nm are the so-called *SuperParaMagnetic Particles* (SPM Particles) [6]. The superparamagnetic particles have considerable magnetic moment and they interact among each other, but when their size is still very small, their magnetic moment is influenced by thermal fluctuations and a magnetic record is hardly realized. With the increase of the particles size, the thermal influence cannot disorient them after magnetizing and they already get an expressed hysteresis cycle. When the size of these particles is commensurate with the thickness of the domain walls, they are called *Single Domain Particles* (SD Particles) and they are always magnetized until complete saturation. Their dimension varies from 18.8 nm up to 31.3 nm [7]. This size is nowadays still in the centre of the technological solutions.

With the increase of the size, the particles become large enough and they contain more than one magnetic domain – this is the region of the multi domain particles (MD Particles) [8], the well known ferromagnetic substances.

When the particles size is known and assumed that one bit could be recorded on each particle, then it is possible to compute the maximal linear record density on one inch.

In case the width of a track is known, the number of tracks per inch could be computed. Fig. 2 shows the alteration of the tracks width, the length of one bit of information and the ratio of width of the tracks per 1 bit for the period 1990-2002.

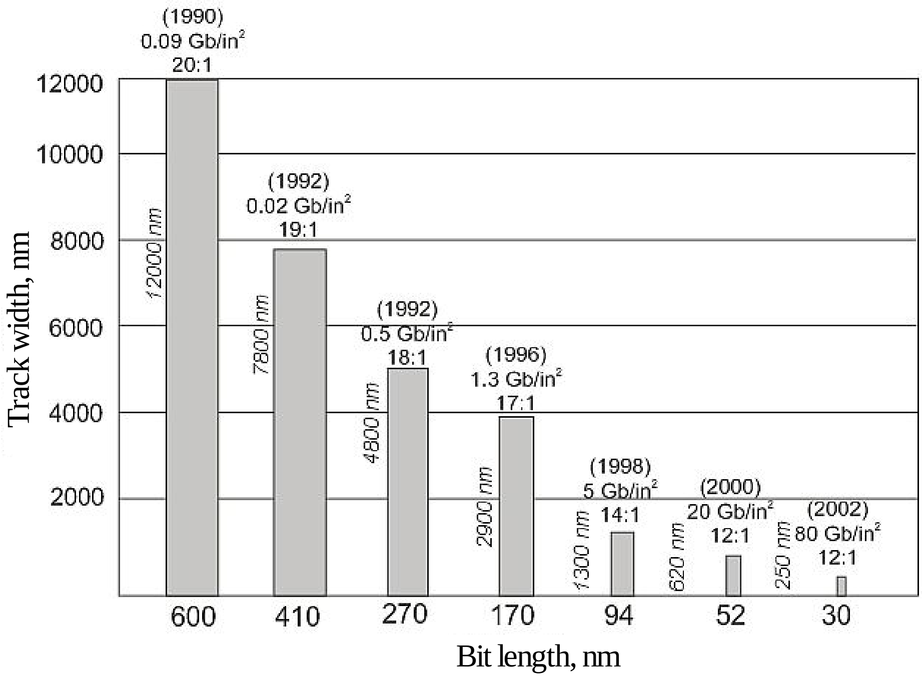

Fig. 2. Alteration of the tracks width, the length of 1 bit of information and the ratio width of the tracks for 1 bit in the period 1990-2002

An expert approach to determine the probable values of the maximal LD and RD

The data LD and RD (TD) of recording contain information about the technological and technical level of production of the storage devices on magnetic hard disks (SDMHD). Most probably due to reasons concerning the know-how preservation, after 2001 all producers state just the AD in Gbit per 1 inch^2 (Gbpin^2).

In order to avoid this lack of data, an expert approach was developed to determine the probable values of the maximal linear and radial (track) densities. This has been accomplished tracing the ratio of the linear density towards the radial (track) density since the design of the first disk device by IBM in 1956 till nowadays (Fig. 3) [9].

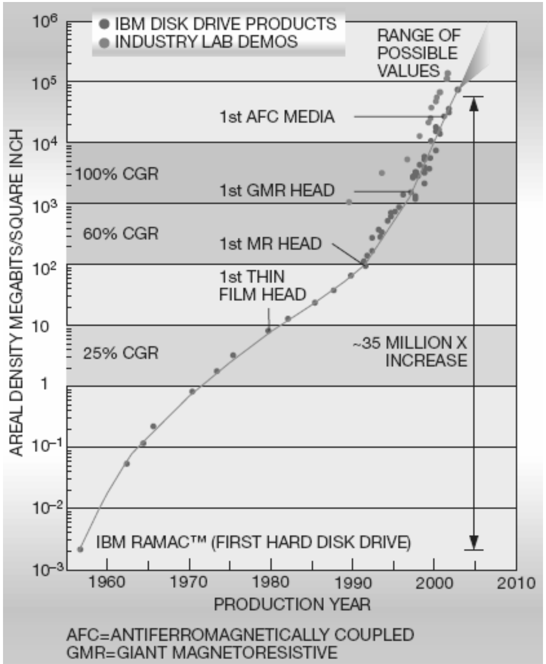

Fig. 3. Hard disk drive areal density trend

This became possible, because up to 2001 all manufacturers and developers gave these parameters as basic indicators as well.

Table 1 shows the data for LD and RD and their ratio for SDMHD, made by IBM (1956-2002).

The data from Table 1 show, that the ratio bpi/tpi diminishes and in 2001 it becomes below 10. Eight is the numerical value of the ratio track width towards length per 1 bit (Fig. 2).

The comparative analysis of the reference data provides reasons to accept the following approach for determination of the probable numerical values of the linear and radial densities, using the areal density only. If towards 2001 the ratio LD to RD

Table 1

No	Year of production	SDMHD	RD tpin	LD bpin	$\frac{bpin}{tpin}$
1	1956	RAMAG IBM350	20	100	5
2	1964	IBM2311	100	1 100	11
3	1968	IBM314-2	200	2 200	11
4	1973	IBM3300-2	407	4 040	10.6
5	1975	IBM3350	484	6 425	13
6	1989	IBM3390	2 235	28 000	12.5
7	2001	Deskstar120XP	57 000	524 000	9

is 8:1, then we may divide AD, which is equal to the product of LD and RD for 1 in^2, by the number 9 and thus obtain the values of the radial and linear density per 1 inch.

However, in 2002 the leading manufacturers have declared very high values of areal density – April 2002, Toshiba – 120 Gbpin^2 [10], May 2002, Fujitsu – 360 Gbpin^2 [11], Seagate Diskon, 2002 (Japan) – 100 Gbpin^2 up to 1 Tbpin^2 [12], Hitachi – 100 Gbpin^2 [13], IBM – coatings with particles size in the superparamagnetic range [14].

In case the approach above described is used, enormous values are obtained for LD. For example at 300 GBpin^2 it equals 3 300 000 bpin, i.e. the particles size is 7-8 nm or far-off in the superparamagnetic area. It is more logical to accept the prognoses of IBM for sharp diminishment of the tracks width, shown in Fig. 4 [14].

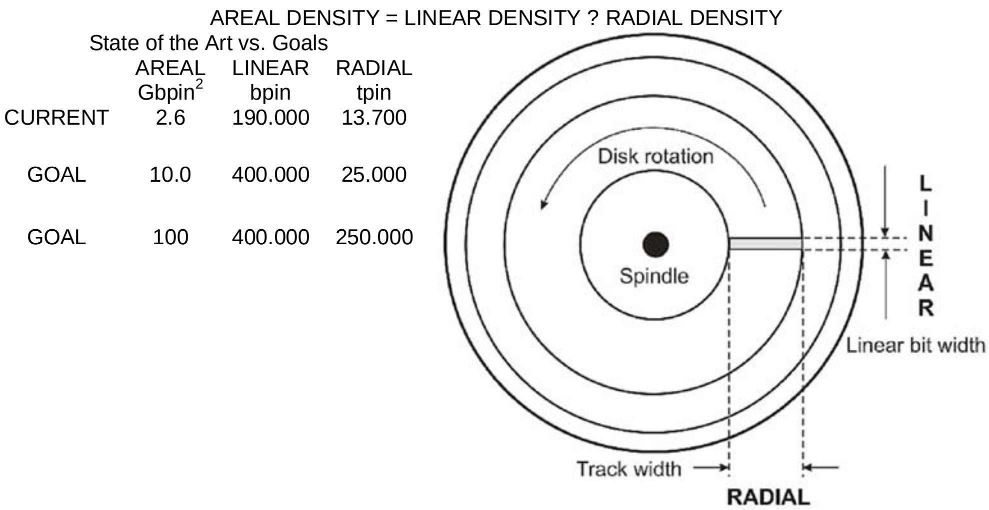

Fig. 4. Magnetic data disk

The data from Fig. 4 indicate that IBM specialists presume the ratio LD per 1 inch towards RD per 1 inch, to be about 2. These prognoses for the example 300 Gbpin^2 lead to reasonable values of LD about 1 000 000 bpin, i.e. within the limits of the dimensions of the single domain particles and RD – approximately 300 000 tpin.

Coefficient of the evolution potential of the main informative features – linear, track and areal density of recording on storage devices on magnetic hard disks

The thin-layer galvanic coatings of magnetic elements or their alloys with particles size in the region of single domain particles and superparamagnetic particle are worthy of note for magnetic recording with high densities. We shall illustrate the maximal record densities – LD in kbpin, RD (TD) in ktpin and AD in Gbpin^2 with the example of Ni-P (Nickel-Phosphorus) alloys [15]. For greater precision and clarity, the numerical data will be given under the following assumptions:

1. One bit of information is recorded on one particle.
2. The thin-layer coatings enable equal density of magnetic record in two perpendicular directions.
3. The areal density of recording is defined as the product of the linear and the track record density.
4. Due to the restrictions of the positioning system, the IBM prognosis is accepted for the maximal TD of recording, that it is twice smaller than LD, at least at the recent moment.
5. The smaller values of record densities under laboratory and/or industrial conditions are due to the constraints imposed by:
   - the qualities of the materials used,
   - the recording methods.
   - technical, technological and design solutions;
   - servo efficiency;
   - efficiency of the error correcting code (ECC Efficiency).

Table 2 shows the theoretically computed values of LD of record, RD of record and AD of record at different size of the particles, comprising the thin-layer magnetic coverings for magnetic recording.

Until 2002 the purpose of the investigators in the field of magnetic recording has been the use of thin-layer coatings with dimensions of the particles in the sector of single domain particles being 20-21 nm. At the beginning of the new century, areal density of recording of 1 Tbpin^2, LD – 2000 kbpin and RD – 500 ktpin have been predicted.

Table 3 shows the maximal values of LD of record, RD of record and AD of record, obtained in laboratory models and/or demo models, developed by leading companies like IBM, Maxtor, Jujitsu, Seagate, Read-Rite, Hitachi Nikkei Electronics [15, 16].

The values of LD, RD (TD) and AD of magnetic recording for the laboratory models show that they have been obtained with particles of a size within the superparamagnetic region. The ratio (LD/RD) is about 3, i.e. close to the predicted by the IBM researchers length of one bit and width of one track [14].

The data from Table 3 indicate that the values of LD, RD (TD) and AD for the demo models, represented at international forums, are comparatively lower.

The values from Tables 2 and 3 for LD, RD (TD) and AD allow the computing of the respective coefficients of their evolution potential. For this purpose it is necessary to accept a conditional limit value of the particles linear dimensions. It is logical that it will be at least twice smaller than this, with which a real record is made. According to

Table 2. Maximal values of LD of record, TD of record and AD of record of particles with different linear dimensions

No	Particle Type	Particle size, nm	LD_{max}, kbpin	RD_{max} (kbpin) at D/TD≈2	AD_{max}, $Gbpin^2$
1	Cluster particles with Very large magnetic moment	< 0.4	Magnetic recording is not realized		
2	Superparamagnetic particles	1.0 5.0 7.5 8.0 9.0 10.0 12.5 15.0 18.0	25400 5080 3400 3200 2820 2540 2000 1700 1410	1270 2540 1700 1600 1410 1270 1000 850 705	3225.80 1290.32 5780.00 5120.00 3976.20 3225.80 2000.00 1445.00 994.05
3	Single domain particles	19.0 21.0 31.0	1340 1210 810	670 605 405	897.80 732.05 328.05

Note. A laboratory model – a model, the results of which have been obtained under laboratory conditions; a demo model – a model, the results of which have been demonstrated on any international forum.

Table 3. Maximal values of LD, TD and AD, obtained in demo models and under laboratory conditions

No	Company	Product	LD kbpin	RD ktpin	AD $Gbpin^2$	LD/RD	Linear size of particles
1	R. Wood & IBM	Laboratory model	1800	580	1050	3	< 12 nm
2	Gao & Bertran UCSD-GMRR	Laboratory model	1800	580	1050	3	< 12 nm
3	M. Mallary & Maxtor	Laboratory model	2800	400	1120	7	< 9 nm
4	R. Victora UM-MINT	Laboratory model	2200	550	1210	4	< 10 nm
5	IBM	Demo model	500	80	40	6	—
6	Read-Rite	Demo model	600	230	130	2.5	—
7	Fujitsu	Demo model	700	150	105	5	—
8	Seagate-Perp	Demo model	850	150	130	6	—
9	Hitachi	Demo model	600	100	60	6	—

Table 3, this size is 9 nm. The prognoses are that recording is also possible on coatings with particles size of 5 nm. Hence this size is conditionally accepted as boundary, and the ratio of bit length towards track width is approximately 2. That is why the limit values of LD is 5000 kbpin and RD – 2500 ktpin, i.e. ratio (LD/RD) H≈2.

The computed values of the coefficients of the evolution potential for LD, TD and AD, shown in Table 4, enable the predicting of the possibilities for the increase of LD, TD and AD of future products.

Since the larger $K_{ЕП}$ is, the greater reserves possesses the potential informative feature, it is obvious that for the linear density LD the highest results were achieved in the company Maxtor – M. Mallary and co-partners, and for Track (Radial) Density-R. Wood from IBM and Gao and Bertran.

Table 4. Coefficient of the evolution potential (CEP) at expert prognosis for LD 5000 kbpin, TD 2500 ktpin

No	Company	Product	LD kbpin	RD ktpin	CEP for LD	CEP for TD
1	R. Wood and IBM	Laboratory model	1800	580	2.80	4.30
2	Gao and Bertran UCSD-GMRR	Laboratory model	1800	580	2.80	4.30
3	M. Mallary and Maxtor	Laboratory model	2800	400	1.80	6.25
4	R. Victora UM-MINT	Laboratory model	2200	550	2.27	4.50

Conclusion

The investigations of the basic characteristics of the informative features – quantity and relevance of the information, show that it is not possible to estimate the potential resources for improving the objects described. In order to overcome this problem, a new criterion for informative features is presented, called evolution potential. The boundary numerical values (theoretical or expert supplied) of the relation of the informative features to the values reached under laboratory and industry conditions is denoted as "coefficient of the evolution potential" (CEP). It is shown that the numerical value of the CEP for the basic informative features of the magnetic information carriers (linear, radial/track and areal density) makes possible the obtaining of a sufficiently convincing estimate of the potential possibilities for their improvement.

R e f e r e n c e s

1. T z a r n o r e t c h k i, O. On a New Criterion for Estimation of the Informative Features of Information Carriers. – Compt. Rend. Acad. Bulg. Sci., **54**, 2001, No 2, 45-48.
2. T z a r n o r e t c h k i, O., D. B o r i s s o v a. Formation of Sets and Subsets of Informative Features of Information Carriers with Magnetic Hard Disks. – Cybernetics and Information Technologies, Vol. **5**, 2005, No 2, 137-142.
3. D a n i e l, E., C. D e n i s M e e, M. H. C l a r k. Magnetic Recording: The First 100 years. New York, IEEE Press, 1998.
4. C h a r a p, S. H. et al. – Trans. Mag., Vol. **33**, 1997, p. 978.
5. A m a m o n, A., J. D u r a n d. – Commun. Phys., **1**, 1976, p. 191.
6. B a c o n y i, I. et al, – Phys. Rev., **B47**, 1993, p. 1491.
7. A h a r o n i, A. – IEEE Trans. Magn., Vol. **29**, 1993, p. 2596.
8. B r o w n, W. F. – Ann. Acad. Sci., **147**, 1969, No 4, p. 463.
9. G r o c h o w s k i, E., R. D. H a l e m. Technological Impact of Magnetic Hard Disk Drives on Storage Systems. – IBM Systems Journal, Vol. **42**, 2003, No 2, 338-345.
10. **http://www.toshiba.com/taissdd/news/press50.shtml, 2002**

11. **http://us.fujitsu.com/news/PR/B0tveCAhAz.html**
12. Dr. Ed Murdock to Discuss Reaching 1 Terabit-Per-Square-Inch Areal Density at DISKCON Japan 2002, SEAGATE SCIENTIST EXPLORES UNCHARTED REALMS OF DATA STORAGE.
http://www.seagate.com/cda/newsinfo/newsroom/releases/article/0,1121,1416%5E4,00.html
13. **http://www.hitachi.co.jp/prod.comp/storage**
14. Albert ("Al") P. Pisano. MEMS Solutions for Data Storage Recent Research Results and Future Trends. Ph. D., 2005.
http://www.me.berkeley.edu/ME219.SP04/Lecture/L03ME219.pdf.
15. Tarnopolsky, Giora J. AREAL DENSITY GROWTH: Is it the Manifest Density of the Hard Disk Drive? March 4-5, San Jose California, 2003, 1-39.
16. Motonobu, Kawai. HDD Recording Density to Reach 500 Gbits/inch2, July 2005 Issue, Nikkei Electronics Asia.
http://neasia.nikkeibp.com/neasia/001583
Websites:
IBM: www.ibm.com
AIST: www.aist.go.jp/index_e.html
Alps Electric: www.alps.com
Anelva: www.anelva.com
Fujitsu: www.fujitsu.com
HGST: www.hgst.com
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