INTELLIGENT INTEGRATED MICRO-NANO-TECHNOLOGIES

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Abstract: *The scientific paper treats new concepts and structures of intelligent integrated micro-nano-technologies elaborated and developed in the frame of research activities and some examples of some implemented technologies (in metrological processes) micro-nano metrological, in micro-nano manufacturing and in laborator processes, in intergronics systems and processes, in intelligent manufacturing of automotive and in micro-nano structures characterization on AFM).The scientific paper presents also the result obtained in measurement process and characterization on AFM, who will be the basis of future research in this domain.*

Key words: *micro-nano-technologies; micro-nano-fabrication; micro-nano-measuring; micro-nano-metrology*

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1. Introduction

The concepts of intelligent integrated micro-nano-technologies (Hall, 2005) is characterized through major transformations in engineering sciences and especially in the integrative engineering that ensures the construction, execution and assembly at large scale at „micro-nano” scale easing the realization of products /micro-products and nano-products and systems/micro-systems and nano-systems and technical, technological and metrological effects at micro-nanometric precisions.

The structure of intelligent integrated micro-nano-technologies, comprises on micro-nano-fields, the newest micro-nano-techniques and micro-nano-technologies, most recent discovered and applied, basing on, on the one side, of micro-nano-tribological principles, sub-granular micro-nano-processing, micro-nano-phase processing, micro-nano-chemical and micro-nano-electrochemical processing and principles of the new intelligent micro-nano-materials, and on the other side the new micro-nano-technological micro-nano-systems, micro-nano-equipments integrated and hyper-integrated with the new CAD/CAM systems.

The matrix of the micro-nano-structure of integrated intelligent micro-nano-technologies, has developed presently, basing on micro-nano-systems / integronized intelligent technological equipments with the intelligent micro-nano-systems/equipments of automated an hyper-integrated control of micro-nano-information micro-nano-engineering.

The scope, application and evolution of intelligent integrated micro-nano-technologies form the strategy of their development, in the sense of increasing competition and capability, flexibility and feasibility, automation and informatization and behaviour and human functions.

The governing of intelligent integrated micro-nano-technologies (Gheorghe et al., 2009), embeds in a process the functions assembly, the conception (architecture, interface and hard-software), the hyper-integrated construction (mechano-electro-informatics at „micro and nano” scale), the processing (technical and technological of information signals), the simulation and modelling (for analyses, algorithms, virtual models, etc), the connection, inter-connection and hyper-integration (complex hybrid architecture), testing and diagnosis (decisional and functioning of the holistic assembly), standardisation (according to European/international norms) and to leading management and coordination (system/isle/network, hyper-integrated technological and holistic).

This new approach „the design towards future of intelligent integrated micro-nano-technologies” (Gheorghe, 2009) commences with their research, development and innovations, for carrying out products/ micro-nano-products / systems, in the new created and developed fields and new fields created and developed such as those comprised in the field of mechatronics depicted in figure 1 too:

- Intelligent and informational engineering/micro-nano-engineering for the high-tech industry and nano-metric metrology;
- „micro-nano”, inspection and expertise of processes and advanced intelligent fabrications processes and products of inspection and expertise systems/equipments;

- Installations and CAD stations engineering / micro-nano-engineering for diagnosing product, technologies and intelligent and hyper-intelligent quality;
- engineering / micro-nano-engineering of systems / equipments / installations of measuring / checking / regulation and control of state and working environment parameters;
- eco-technological engineering / micro-nano-engineering for evaluation, diagnosis and monitoring of „white houses” designed for intelligent micro-nano-fabrication and high-tech products testing;
- intelligent micro-nano sensors and micro-nano actuators engineering / micro-nano engineering, destined for the integration of intelligent advanced micro-nano products / systems;
- engineering / micro-nano engineering of intelligent micro-nano CIPs;
- engineering / micro-nano engineering of intelligent micro-nano robots;
- engineering / micro-nano engineering of intelligent fabrication (micro-nano-processing; micro-nano-coding; micro-nano-lithography etc)
- etc.

Fig. 1. Mechatronic micro-nano-technologies

2. Exemplification of intelligent integrated micro-nano technologies

2.1 In metrological and micro-nano-metrological products (Gheorghe, 2009)

The applications of integrated intelligent micro-nano-technologies at The National Institute (INCD) Mechatronics and Measurement Technique – Bucharest, Romania by the authors of the paper, refer to:

- exploring, measuring and control of micro-nano-geometry and surface macro-geometry:
 - a) for metrological measurements and micro-nano-metrological of roughness, by contact and non-contact methods (fig.2 and fig.3);

Fig. 2 Metrological measurements and micro-nano-metrological of roughness device

Fig. 3. Metrological measurements and micro-nano-metrological of roughness tool

The explored, measured and controlled parameters are: R_a ; R_x ; R_T

b) for metrological and micro-nano-metrological macro-geometry of surfaces (circularity, profile, concentricity, coax positioning, perpendicularity, parallelism, etc), (fig.4);

Fig. 4. Metrological and micro-nano-metrological surface macro-geometry measuring

- exploring, measuring and metrological control and micro-nano-metrological control of heights of pieces, by contact methods (fig.5)

Fig. 5. Exploring, measuring and metrological control of piece

- exploring, measuring and metrological control and micro-nano-metrological control of 3D topography by AFM (fig.6)

Fig. 6. Exploring, measuring and metrological control of 3D topography by AFM

2.2 In intelligent micro-nano-fabrication processes:

The intelligent integrated micro-nano-technologies for micro-nano-fabrication processes, are adapted to the dimension intervals $(10 \div 1) \text{mm}$ / $(1 \div 0,001) \text{mm}$ / $0,001 \text{mm} \div 1 \text{ nm}$ and nano-structures that characterize electric, magnetic, optic, thermal, mechanical, tribological, etc. proprieties at nano-metric and under-nano-meter scale.

The mechatronic and integronic technologies for micro-nano-fabrication encompass the „top-down and bottom-up” techniques, that analyzes the approaches similar to the lithography and micro-nano-processing techniques and respectively approaches chemical engineering and the science of materials, that is, molecular recognition and auto-assembly (molecules, colloids and groups).

The mechatronic and integronic technologies for micro-nano-fabrication, the best known and applied technologies used in research-experimentation and industrial laboratories, are mainly:

- micro-nano-fabrication with electron beam and nano-impressing (fig.7), with micro-diagrams realized by AFM and quartz matrix (fig.8).

Fig. 7. Micro-nano-fabrication with electron beam and nano-impressing

Fig. 8. Micro-diagrams realized by AFM and quartz matrix

- micro-nano-fabrication by epitaxy with atomic precision, by molecular beam, and chemical disposition of metal-organic vapours (fig.9), but also by self-assembly induced by bending (fig.10);

Fig. 9. Molecular beam, and chemical disposition of metal-organic vapours

Fig. 10. Self-assembly induced by bending

- micro-nano-fabrication of probe scanning, by STM and AFM (fig.11);
- Etc.

Fig. 11. Micro-nano-fabrication of probe scanning, by STM and AFM

2.3 In integronic processes and systems:

The intelligent integrated micro-nano technologies used in integronic processes and systems (fig.12), must identify and establish the „input values - x_i ”, „output values - x_e ” and „harmful values” - x_p ”, respectively the cause, effect and perturbation values.

Fig. 12. Integronic system

The expression of the correlations between the values of the integronic system in made in mathematical language by differential equations whose solutions allow the

assessment of static and dynamic behaviour of the integronic systems and its integronic sub-systems that comprise it.

Taking into consideration the integronic system with a single entry value, X_i , and with a single output value, X_e , then the correlation of these two is given by the following differential equation:

$$a_n \frac{d^n x_e}{dt^n} + a_{n-1} \frac{d^{n-1} x_e}{dt^{n-1}} + \dots + a_1 \frac{dx_e}{dt} + a_0 x_e = b_m \frac{d^m x_i}{dt^m} + b_{m-1} \frac{d^{m-1} x_i}{dt^{m-1}} + \dots + b_1 \frac{dx_i}{dt} + b_0 x_i \quad (1)$$

where:

$$x_e = \sum_{i=1}^n x_{ei} ; \quad x_i = \sum_{i=1}^m x_{ii} ; \quad (2)$$

and the solution if this equation is as follows:

$$x_e = x_e(t) + x_f(t) \quad (3)$$

$x_e(t)$ = general solution of the homogenous equation corresponding to the equation (1);

$x_f(t)$ = particular solution

$x_e(t)$ = characterizes the free regime, reason for which this component is called free;

$x_f(t)$ = characterizes the forced regime;

The free regime of the integronic process or system is identified and accordingly the function that expresses the variation in time of the input value (or the several variables); in the « excitation » function, the functioning regime and the transfer function are concentrated, this being expressed, after the Laplace transformation of the output measure and the input value, as it follows:

$$Y_{(s)} = \frac{x_e(s)}{x_i(s)} = \frac{b_m S^m + b_{m-1} S^{m-1} + \dots + b_1 S + b_0}{a_n S^n + a_{n-1} S^{n-1} + \dots + a_1 S + a_0} \quad (4)$$

This transfer function allows a characterization of the behaviour of the integronic process or system..

After that, the following characterizations can be made:

- Identification of the concentrated and / or distributed parameters;
- Identification of the multi-variables of the input and output system;
- Identification of the variations of the input and output values;
- Identification of the behaviour of the integronic processes and system as process or varied or invariant system, or as „deterministic process or system” or as „stochastic process or system”

- The qualitative and quantitative appreciation and of the „value that characterizes the whole system or integronic process”;
- The fundamental investigation instruments of the integronic process or system, starting with „modelling engineering” and continuing with „mathematical modelling” and other „electric and informatic modelling”;
- The newly conceived integronic process or system is designed, realized and informatized.

2.4 In adaptronic processes and systems:

The intelligent micro-nano-technologies used in adaptronic processes and systems, must identify and establish the adaptronic techniques and instruments, according to the hyper-integrated architectural structures and mechatronic and integronic processes realized by them.

Thus, the adaptronic concept binds research, innovation and application and mechatronic and integronic constructions, destined to the processes and technologies realized by high-tech advanced products and systems.

Adaptronics, as an advanced science and engineering is part of the Nano-sciences and Nano-technologies of the XXIst century, realizing at any “macro-micro-nano” scale, assemblies of hyper-integrates and hyper-intelligent systems, accepted as unique and sustainable solutions, for the competitive development of the new knowledge-based economy.

Adaptronics, stated by the authors of the papers, in both structural and functional control at hyper-integrated – hyper-intelligent control, is used as a science and integrative and holistic science and engineering for the hybrid development and mix development of the new high advanced technical and technological areas:

- The area of the new “intelligent sensoristics”;
- The „intelligent actuatronic” new area;
- The new area of „intelligent and integrated control”;
- The „automated and intelligent” new area;
- The “intelligent micro-nano-technologies” new area;
- The „intelligent materials” new area;
- The „nano-measuring and nano-positioning” new area”;
- The „ structural analysis and basing on finite element analysis” new area;
- The „high-tech profile” new area
- The „certified monitoring and diagnosis” new area;
- The „systems foe mobile applications” new area;
- The „laboratories with mobile applications for military and civilian character” new area;
- The new area of cooperation „with partners in the industry, university, institute and state authorities”;
- etc.

3. The results of intelligent micro-nano-technologies integrated in the field of mechatronic and integronic technologies of integrated control implemented in the intelligent fabrication of automotives

The results of research and innovation in the field of integrated control of mechatronic and integronic equipments (Gheorghe et. al., 2009) at INCD-Mechatronics and Measurement Technique in Bucharest-Romania, were implemented in the intelligent fabrication of automotives at SC Renault-Dacia Pitesti in Romania.

The following are examples of such mechatronic and integronic equipment.

3.1 Intelligent mechatronic installation for air charter air-tightness and clutch mechanisms and TL8 differential plant (fig. 13)

Fig. 13. Intelligent mechatronic installation for air charter air-tightness and clutch mechanisms and TL8 differential plant

- Equipment presentation:
 - The mechatronic complex installation is a mono-block installation composed by two installations of air-air clutch carters and mechanism carter;
 - The work circle is automated;
 - The management of the process is made by an intelligent measuring programme;
 - The basing of the piece is ensured by the tightness board;
 - The introduction of the piece in the measuring process id done using the mobile platform;
 - The architecture of the piece for tightening by bracket and capping sub-assemblies;
 - The measuring process by ATEQ call;

- The checking of pressure loss is done according to French / international norms;
- The result of the checking is automated.
- Technical and functional characteristics:
 - Work pressure: 5 bar;
 - Checking pressure: 0,2 bar;
 - Admitted pressure loss: $0,25 \text{ cm}^3 / \text{s}$;
 - Precision: $\pm 0,02 \text{ cm}^3 / \text{s}$;
 - Duration of a cycle: $\sim 40 \text{ sec} / \text{piece}$;
 - Electric energy: 220 V / 50 Hz

3.2 Intelligent mechatronic machine for dimensional control and marking “Reversing module - MdR” (fig. 14)

Fig. 14. Intelligent mechatronic machine for dimensional control and marking “Reversing module - MdR

- Machine presentation:
 - The machine is made up of:
 - Two posts measuring the following rates:
 $C=144,2\pm 0,05$ and $d_{cc}=92,1\pm 0,05$;
 - $d_{cs}=112 \pm 0,05$ and $k=17,1 \pm 0,05$;
 - 1 DATAMATRIX marking posts and video camera;
 - 1 computer.
- 1 operator panel;
- 1 automation unit;

- 1 pneumatic panel;
- 2 immaterial optical barriers;
- 1 thermal measuring compensation system;
- The measuring is electronic with photoelectrical transducers;
- Technical and functional characteristics:
 - Duration of a cycle (measuring + marking) : 85 s / piece;
 - Intelligent measuring precision: $\pm 0,005$;
 - Power : 220 V.c.a. / 50 Hz;
 - Working pressure: $5 \pm 0,2$ bar;
 - Programmable automate : Siemens;
 - Measuring and control process: automated, intelligent;
 - Exploitation mode: 100% control.

4. Results of intelligent micro-nano-technologies iintegrated in the field of AFM mecahtronic and integronic equipments

INCD-Mechatronics and Measurement Technique, Bucharest, Romania, has implemented and experimented, through the authors of the paper, the technology of atomic force microscope (fig. 15) for the thorough characterization of surfaces type thin film or surfaces of existing devices, with the aid of a measuring tip attached to a cantilever.

Fig. 15. AFM and related devices

Using an AFM, the roughness of femur heads of several hip prostheses was determined. The prostheses used in the studies of INCDMTM for the characterization by AFM (NTEGRA NANOLAB) made up of stainless steel.

After these characterizations, the disposition of thin layers was observed, these layers being meant to improve the hardness of prostheses and thus extend their use.

With the use of AFM, the surface of the femur heads were studied, scanned and analyzed in 3D.

By the use of software, surface roughness was obtained, with values between 15 and 80 nm, the video being made at a resolution of 1 nm (fig.16).

Fig. 16. Software modelling for measuring surface roughness

The concrete results obtained in the AFM measuring process are shown in table 1.

No. of crt.	The size of the measured surface	Measured roughness
0	1	2
1	(140 x 140) μm x 150 nm	21.24 nm
2	(100 x 100) μm x 100 nm	15.62 nm
3	(140 x 140) μm x 300 nm	89.99 nm
4	(130 x 130) μm x 300 nm	27.069 nm
5	(70 x 70) μm x 140 nm	24.27nm
6	(120 x 120) μm x 100 nm	15.596 nm
7	(75 x 75) μm x 155 nm	20.28 nm
8	(75 x 75) μm x 150 nm	33.37 nm
9	(180 x 175) μm x 75 nm	27.224 nm
10	(65 x 65) μm x 50 nm	15.447 nm
11	(90 x 90) μm x 25 nm	80.86 nm

Tab. 1. Results of measuring process on AFM

5. Research contributions and perspectives

The research contributions are identified by elaborating new concepts, structures and matrices of intelligent integrated micro-nanotechnologies, through virtual simulation and processing, through projecting, realisation and integration of microsystems and microtechnologies for surface metrology and surface topography by AFM, for scanning the samples, for intelligent manufacturing of automotive, etc.

In perspective the results of results presented in the scientific paper are the basis for future research plans, being in the same time and next steps to be realised:

- development and scientific fundamentation of new mentioned abordation from this paper;
- projecting, construction and innovation of advanced solutions for micro-nano high tech systems of nanometric metrology, inspection and expertize, diagnosis, micro-nano calibration and micro-nano manufacturing monitoring;
- experimental researches of physical models compared to virtual models, on micro-nano systems categories and micro-nano equipments;
- integration the results research of this scientific paper and the continuation with future results of future research plans.

6. Conclusions

Presently and especially in the future, Intelligent Integrated Micro-Nano-Technologies go through a development and especially, a sensitive growth of their applications in industrial processes and laboratory processes as well, leading to a high technical and scientific potential and to a full, complex, generative and multi-productive integration on advanced intelligent knowledge.

The Intelligent Micro-Nano-Technologies presented in the paper by the authors, by the stated examples, prove the orientation of the institute (INCD-MTM) on the same European direction and strategy in the advanced high-tech field.

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