BIONIC IMPACT ON INDUSTRIAL PRODUCTION DEVELOPMENT

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Summary

Any machine-tool or process designer by engineers is not as excellent as alive organisms, which manufactured the Nature in evolution process. Very intensive technology development encourages engineers for looking for new original solutions. Because of this fact engineers very often are looking for inspiration in natural surroundings. The bridge between solutions occurring in natural surroundings and technique create the area of knowledge named the “bionic”. In the paper the general methodology of bionic designing objects or processes and chosen applications of bionic achievements in technical area are presented.

Keywords: bioinspiration, stiffness, surface structure, fatigue strength, wear resistance

1. Introduction

Bionic (from Greece bios – life and mimesis – mimic) it is interdisciplinary branch of science which investigate the alive organisms (plants and animals), material and processes occur in natural surroundings in order to apply results in technique [1-7]. The Man from its beginning observed phenomena, processes and alive organisms in order to solve basic problems of his life. Now, thanks to the science and technique development the above mentioned observations are more precise and can be widely applied in architecture, machine building, automation,

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2. The main areas of bionic application

From literature review results that in the natural surroundings exists 55,000 species of mammals, ~31,000 of fishes, 10,000 of birds, 8,800 – of reptiles, and ~1,000,000 of insects and ~300,000 of plants. Each of this animals or plants created in evolution process original solutions which can be used as a pattern and model for objects mechanical shape and structure, surface structure or process design. Scientists evaluate that now people are able to take advantage from about ~10% bionic solutions [1-3]. In order to find out general trends of bionic application the analysis of 218 papers have been undertaken. From this analysis results that in 28 papers the source of inspiration were mammals, in 20 fishes, in 11 birds, in 9 reptiles and in 46 insects. The number of papers as function of distributions: problems (material, movement, function& behavior, sensor) and stages of development (Idea, Research, Prototype, Product) is presented in the Fig. 1 [1].

Fig. 1. Distribution of problems (Material, Movement, Function & Behavior, Sensor) and stages of development (Idea, Research, Prototype, Product), based on [1]
Similar investigations have been done taking into account patents in the field of “bionic” in USA in years 1976-2006 (147 patents). General results are presented in Fig. 2.

![Fig. 2. The main fields of bionic achievements application, based on [2]](image)

It is also worth to underline that number of patents per year increase in from 1 patent per year in period: 1977-2000 up to 16 in year 2006. From general outlook results that this tendency in increasing number of patents and papers is actual. During last ten years number of articles and patents significantly increases. The special Journals which publish only papers connected with “bionic research” have been arisen. So, it is right to evaluate that now during each year a few hundreds of paper and a few tenths of patent is published.

### 3. Methodology of bionic design

Precise and general methodology of transferring solution from the Nature to technique has not been working out yet. It is a question if it is possible at all, because to work out such a general methodology acting without intuition of engineers is impossible on this stage of bionic development. It result from the fact that in each individual case there are different tasks to solve and different phenomena for mathematical modeling and experimental verification. On base of published papers it is possible to formulate the general steps in bionic designing new objects or working out the new processes [1-22]. In biological inspired process or object development it is possible to distinguish two general cases.
A. The technical problem is defined and researches are looking for its optimal solution in natural surroundings.

B. In the natural surroundings the interesting processes, material, plants or animals structure was identified and researchers are looking for optimal technical application.

The literature review indicate that case „A” is more frequent in practice. From literature review results that biologically inspired technical problem solution can be carried out in the following stages [1-22].

1. Technical aim formulation.
2. Biological structures, materials or processes analysis in order to find out biological model for technical problem solving and primary evaluation of this model.
3. Mathematical modeling of mechanical structure or process on the base of biological model; here very often Finite Element Method is applied.
4. Taking into account the results of modeling the material model of the object or test stand for process investigations is created.
5. Experimental investigations of the material model (stiffness, stresses and distortions distribution, weight, fatigue resistance, wear resistance) or process (relation between input and output parameters) are carrying out.
6. On the base of experiments from point No 5 usually it is possible to evaluate bionic model of the object or process and introduce procedure of correction or building prototype of the object or process. It is worth to underline that the very important research tool in above presented methodology is intuition.

4. Biological inspirations in aircraft and car industry

4.1. Bionic inside structures design

It is worth to underline that animals and plants in natural surroundings have been developed in lasting millions years evolution process. Because of it the structures, surfaces and shapes which can be finding in the natural surroundings are very efficient but usually complicated and difficult for copying in technical applications. Usually it is possible to design advanced bionic objects with very high properties and low weight but in each case the methods of bionic object manufacturing should be taken into account. The high properties of the objects can be reached by using special shape or special inside structures or special structures of detail’s surface. Examples of above specified cases will be presented below.

In airplane or car industries the very important problem is weight of parts. So it is the first reason that engineers are looking for inspiration investigated first of all birds and mammals skeletons, structures of plants as bamboo, bulrush, Mexico
cacti, Brazilian Giant Horsetail, grass or ordinary trees [3-5]. The information for light weight design can be also taken from inside structure of bones, birds beaks, tree stems, branches and plant’s leaves.

Fig. 3. Photographs of biological structures which have been used for lightweight design of Pylon Radar Cross Section, based on [15]

Fig. 4. The measuring system for target’s Radar Cross Section, based on [14]

Pylon Radar Cross Section was designed using biological models of bulrush and bamboo (Fig. 3). Specific strength efficiency and specific stiffness efficiency of
bionic pylon increased by 52.9% and 43.6%. Bionic pylon mass was decreased by 43%; the same surface of RSC was also decreased [14]. In some aircraft details design as a biological model the bamboo cross section structure was taken into account (Fig. 5).

![Fig. 5. Bamboo’s hierarchical structure in different scales, based on [15]](image1)

![Fig. 6. Bionic model of a crossbeam made by investment casting, based on [15]](image2)

### 4.2. Special bionic surfaces design

The second important problem in production are special surfaces. In practice usually the relation between surface layer properties and functionality of details occur. In the Nature engineers can also find inspirations in this area. It is worth to underline that in the Nature there are not smooth surfaces [3-5, 16]. For example skin of shark, snake or body and wings of insects (dung beetle, butterfly) have very complicated and sophisticated structure [16]. Thanks to it these animals can move with low resistance in water, air or soil. For example the special structure of shark skin make him possible to flow with velocity ~60 km/h (Fig. 7). These surfaces find wide applications in many areas. For instance a special material with structure similar to shark skin was use by Lufthansa on aircraft body in order to decrease resistance during flight and decrease fuel consumptions.
Another example of surface designing with a special structure is presented in Fig. 8. This aircraft frame with a special surface structure has very high stiffness and pressure resistant properties.

4.3. Special shapes design

The third important problem in airplane and car industry is object’s optimal shape. It is easy to noticed that in the Nature the regular and flat shapes don’t occur [3, 5]. It results from the fact that body of animal must be optimal for its living condition. If not, the animal has not a chance to survive. There are many technical solutions inspired by animals shape. Tropical “boxfish” (Fig. 9) was for Mercedes Company a model for building “bionic car” (Fig. 10) with very low
movement resistance and small oil consumption (2.8 l/100 km) when speeding ~100 km/h [20]. Penguins, and birds were models for ships and aircraft designing or development. Penguin is very awkward on the land but in the water is wonderful swimmer. Because of it engineers would like to take the shape of its body as a model for large aircrafts design [5].

Fig. 9. Tropical fish – “boxfish” – has coefficient of movement resistance only 0.06, so it was taken as bionic model for building „bionic car”, based on [18]

Fig. 10. Mercedes bionic car : l = 4.24 m, w = 1.82 m, he = 1.59 m, max. speed = 190 km/h, based on [18]

For bionic car resistance coefficient $C_d = 0.19$ while for conventional car from series production $C_d = 0.27$; Mercedes bionic car is equipped with System of Selective Catalic Reduction (SCR) – because of low oil consumption and SCR system this “bionic car” is very friendly for environment. On the base of above examples, there is no doubt that in order to improve any technical object (machine unit, detail or processes) engineers can find the inspirations in the Nature.
Summarising these short considerations it is worth to underline that the Nature not only offers inspirations for solving technical problems but in the same time remind us that “the Man” is only a part of natural surroundings.

5. Bionic inspirations in tooling and machine tools design

5.1. Crossbeam structure of Lin MC6000 machining center

One of important problem in machine – tools design is quality of machine – tool body, as: weight, stiffness, distortion and anti-vibration properties. There is no doubt that between machine – tool quality and machining accuracy is close relation. Similar situation is with high loaded precision parts of tooling. Some examples of typical bioinspirations models in designing lightweight units with high mechanical properties are presented below [12, 13, 19, 20].

The ordinary tree (stem or branches) have optimal shape an dimensions from load bearing and stresses distributions in nodes. Tree’s leaves also have very interesting inside structure of veins. Leaves can resist against wind pressure thanks strength and elasticity of its material and veins inside structure. They can also change (adopt) their position in relation to sun beams. Some leaves inside structures are presented below.

The structures presented in Fig. 11 and 12 were the biological models for design movable Crossbeam structure of Lin MC6000 machining center. It is a 5-axe gantry type milling machine.

Static experiments proved that in bionic model (Fig. 13b) it was possible to decrease weight of ~3.31%, decrease maximal deformation of ~16.22% and
increase a specific stiffness of \( \approx 23.29\% \). Dynamic experiments proved that the first natural frequencies of the bionic model are increased of \( \approx 22.76\% \) and \( \approx 24.32\% \) respectively. So, it can be concluded that anti-vibration properties of bionic model are improved (Fig. 14).
5.2. The bionic design of precise grinding machine – tool units

In below presented examples the bionic design was worked out for improving precise grinding machine-tool bed and column [12]. The general view of precision grinding machine-tool is presented in Fig. 15. The aim of this works were increasing the stiffness, decreasing weight and distortion and improve anti-vibration properties (it means increase natural frequencies). As a biological model for machine tool bed and Column the leaves of plants with its specific structure of veins have been also taken into account (Fig. 16) [12, 13].
After Finite Elements modeling the structure of machine–tool bed can be improved as it is presented in Fig. 17.

Taking into account Figs:17 and 18 it is possible to find out relations between the redesign stiffener layout in machine-tool bed and leaf venations [18]. From experiments results that bionic model of machine–tool bed in comparison to
conventional one has a slightly increased weight of ~0.87% but maximal deformation decreased of ~12.07% and stiffness of guides increased of ~12.30%. The general conclusion resulting from experiments is that machine – tool bed was significantly improved.

The another important work was to improve design and properties of machine-tool column sliding horizontally (Fig. 15) [12]. Using analogical methodology and using leaves as biological model it was possible to improve significantly machine-tool movable column. After experimental tests it was possible to conclude that maximum deformation of the bionic column is reduced of ~23.60% while weight was decreased of ~1.31%. The first frequency was improved – increased by ~18.55%. The general conclusion from experiments is that machine – tool column static and dynamic properties were significantly improved.

Results of above presented research [12, 13] make it possible to design bionic grinding machine-tool with improved bed and movable column what gives the possibility to reach higher machining accuracy in comparison to conventional grinding machine – tool.

5.3. Thin-walled cylindrical structures

Thin-walled cylindrical structures are widely applied in different equipment – also in machine-tool’s tooling. Their conventional representative and dimensions and range of applications are presented in Fig. 19 and 20.

Here as a biological model the bamboo cross section of bamboo was taken into account (Fig. 21). Taking into account above presented general methodology the algorithm for bionic design of cylinder from Fig. 19 was worked out (Fig. 22).
Taking into account result of bamboo research in macro and micro scale, according presented in Fig. 18 algorithm a bionic cylindrical shell structure was designed (Fig. 23).
Fig. 22. The flow Chart of cylinder bionic design, based on [20]

Fig. 23. Bionic cylindrical shell based on bamboo cross section, based on [20]
From the comparison of conventional and bionic cylinder shell it results that load bearing efficiency (kN/kg) for bionic design is ~124.8% higher than for conventional one (Fig. 19).

6. Manufacturing problems

Bionic structures are quite different from conventional one. For manufacturing conventional parts engineers developed advanced systems, which application for manufacturing bionic details sometime is limited. It results from the fact that bionic structures are usually more complicated then classical. Because of it the best way for manufacturing bionic details is additive methods applications. However sometimes it could be very difficult because some bionic details are very large – for example: Crossbeam structure of Lin MC6000 machining center Fig. 13. In these cases the welding technologies are very useful. For medium precise parts it is possible to apply investment casting technology. In case of surface structuring (Fig. 6) the milling, laser (LBM) or electro-discharge (EDM) machining can be applied [3]. For smaller bionic details manufacturing the application of Laser Additive Manufacturing could be efficient way for production. In this case very helpful could be equipment produced by Nanoscribe Company – which offers manufacturing small parts with resolution of micrometers [22].

7. Conclusions

The bionic builds a bridge between “world of plants, animals and processes” developed by the Nature in evolution process and technical applications. Using “bionic” solutions it is possible to solve satisfactory technical problems connected with:

• precise machine-tool units and parts designing (lightweight construction with improvement of some mechanical properties as: stiffness, strength or distortions),

• improvement of surface layer and details properties by creation on the surface patterns analogous to those worked out by the Nature in order to increase: stiffness, fatigue strength resistance or pressure resistance.

Taking into account above presented methodology and some biological inspirations it was possible to work out bionic design of machine-tools units or tooling, which have achieved: higher load bearing efficiency of ~124%, increase of stiffness of ~21-43%, weight decrease of ~3-43%, distortion decrease of ~16-44% [9-15]. In each case where dynamic experiments were carried out the anti-vibration properties of units or parts were also improved.

In some cases improvement of details properties is possible only when complicated bionic structures are applied. In this case the problem of
manufacturing arise. Here the advanced forming, joining, additive or removal processes should be applied. This fact of course increase costs of production but usually gains from object quality, its life time increase and material consumption decrease are significantly higher.

References


[22] www.nanoscribe.de

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