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PNEUMATIC POWER SERVO-MECHANISM MADE FROM POLYMERIC MATERIALS – ANALYSIS AND OPTIMIZATION

На сучасному світі, люди все більш і більш часто стикаються із завданнями, небезпечними для їх здоров'я і життя взагалі. Такі завдання визначають всесвітньо відомі тенденції в розвитку військової промисловості також як і збільшення в рівнях загрози для цивільних осіб, представляючи все більш і більш часто має на меті в терористичних нападах. Тому легко звернути увагу на істотне зіткнення інтересів. Конструюючи ракету, бомбу або раковину, конструктор цілиться в запобігання його роззброєнню будь-якими третіми партіями. Для цього кінця, різні види датчиків використовуються, маючи на меті вибух пристрою, коли відпущено. Різні види датчиків можуть використовуватися наприклад радіо або електромагнітні wave датчики, металеві детектори, і тому подібне Доступні нові виробничі технології також як і з'являючись нові пластмасові матеріали з властивостями, відповідними різним специфічним вимогам, примушують замінити металеві елементи все більш і більш часто складеними конструкціями.

У цьому папері, ми представляємо проблему проектування нового пневматичного енергетичного допоміжного механізму, зробив цілком від полімерних матеріалів. Цей папір зосереджується також на напруженості елементу проектувальника також як і інші проблеми мали відношення з тривалістю і ефективністю компоненту в питанні.

Об'єктна тема до експертизи охоплює один з головних компонентів маніпулятора, проводив цілком від пластмасових матеріалів. Одна з найголовніших особливостей запропонованого рішення - усунення небажаного відгуку датчиків, намагаючись роззброїти надану ракету. Додаток пластмасових матеріалів вимагає проте відповідний проект, проводячи і перевіряючи індивідуальних компонентів в деякому відношенні відмінний від поточних компонентів проводив від металевих матеріалів. Для цієї мети, ми експлуатували комп'ютерне програмне допомагають забезпечення проекту, що спеціалізується для таких завдань.

In the contemporary world, people are increasingly frequently faced with tasks dangerous for their health and life in general. Such tasks are determined by the world-wide trends in the development of the military industry as well as the increase in the threat levels for civilians, representing increasingly frequently targets in terrorist attacks. It is therefore easy to notice a substantial conflict of interests. When constructing a rocket, bomb or a shell, a constructor aims at preventing its disarmament by any third parties. For this end, various types of sensors are used, targeting explosion of the device when tempered with. Various types of sensors can be used e.g. radio or electromagnetic wave sensors, metal detectors etc. The available new manufacturing technologies as well as emerging new plastic materials with the properties meeting various specific requirements cause the metal elements to be replaced increasingly frequently by composite constructs.

In this paper, we present the problem of designing a new pneumatic power servo-mechanism, made completely from polymeric materials. This paper focuses also on the tightness of the designer element as well as other issues related with the durability and efficiency of the component in question.

The object subject to the examination comprises one of the main components of the manipulator, manufactured completely from plastic materials. One of the most important features of the proposed solution is the elimination of the undesired reaction of sensors when attempting to disarm the given missile. The application of plastic materials requires however appropriate design, manufacturing and testing of individual components in a way different from current components manufactured from metal materials. For this purpose, we exploited computer aided design software, specialised for such tasks.

1. Introduction

In the contemporary world, people are increasingly frequently faced with tasks dangerous for their health and life in general.Therefore, the production automation is under intense development, since human beings are replaced by various types of manipulators and robots.There is a wide variety of such devices manufactured from metal materials, though in everyday life there are areas of application where the presence of metal material is highly undesirable.The available new manufacturing technologies as well as emerging new plastic materials with the properties meeting various specific requirements cause the metal elements to be replaced increasingly frequently by plastic constructs.

In this paper, we present the problem of designing a new pneumatic power servo-mechanism, made completely from polymeric materials. The object subject to the examination comprises one of the main components of the manipulator, manufactured completely from plastic materials. The application of plastic materials requires however appropriate design, manufacturing and testing of individual components in a way different from current components manufactured from metal materials. For this purpose, we exploited computer aided design software, specialised for such tasks.

2. Pneumatic drive

The pneumatic drive was selected from a plethora of available drive types, which can be potentially used to affect the manipulator displacement. A generic pneumatics is one of the increasingly frequently and commonly applied techniques in terms of mechanization and automation of the production processes. Compressed air is the main power source in the pneumatic drive and control systems, which when compared to other power sources has a number of advantages, including:

- simple storage and transport,

- resistance to changes in the ambient temperature,
- safe utilization conditions (leakage of compressed air into ambient are not harmful and do not cause potential fire hazard).

One of the advantages of the pneumatic systems is their high durability and operating reliability under a wide range of temperatures and in various environmental conditions. The said systems have also the advantage of high resistance to overload as well as simplicity of operation, maintenance and repairs, resulting thus in lower installation investment. A pneumatic servo mechanism is the basic executive element for this particular type of solutions – it is a mechanical device, which transforms changes in the pressure of the air or some other gas into displacement. By delivering gas under pressure higher than the atmospheric pressure (or lower than the atmospheric pressure) to one of the chambers of the servo mechanism causes the displacement of the piston inside of the cylinder of the servo mechanism, thus causing the displacement of the operating grappler attached to this piston. The construction of the servo mechanism determines whether the displacement will be longitudinal or angular and whether when the supply of pressurized gas is disturbed, the location of the piston rod of the servo mechanism is locked or whether it will be displaced to the terminal location.

3. Analysis of materials used for plastic components

3.1. Improvement of material parameters by adding admixtures

The thermoplastic materials were analyzed in detail below. Such materials can be further reinforced by adding glass fibers, other mineral substances or even glass balls. The optical fibers used in the thermoplastic materials significantly increase the resistance, rigidity and the operating temperature. Glass balls and other mineral substances increase the mechanical resistance to a lower degree though significantly prevent the mould warping i.e. the so-called the contraction anisotropy.

The application of glass fibers significantly deteriorates one of the processing parameters i.e. the so-called processing contraction (it is smaller along the orientation of the fibers).

Modern composite materials are formed from a combination of various types of fibers – they are typically referred to as the hybrid reinforcement. Aramid and coal fibers are used typically for this purpose. The properties of the composite materials containing hybrid reinforcement are much better, especially in terms of special applications. They typically meet the expectations of the end customers in a better way when compared with the traditional composite materials, using a single type of reinforcement. It is also worth mentioning that the polymers are isotropic (excluding the oriented crystalline thermoplastics) and have viscous elasticity, while their properties are strictly dependent on the temperature and the load duration. The fibers are on the other hand anisotropic and have the properties of an elastic body.

3.2. Young module

The rigidity of a flat plate subject to bending forces depends on the Young module, characteristic for each particular material (E) as well as the geometric moment of inertia of the plate cross-section. The said module is defined as the ratio of the normal stress σ to elongation ε.

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

When considering partially crystalline materials, it is necessary to realize that uncontrolled thickening of the walls (e.g. in order to increase the product rigidity) is often the main cause of other problems. A change in the thickness of the element walls, manufactured from materials reinforced with glass fibers, automatically generates changes in the direction of the fiber orientation, following the flow direction only in the proximity of the mould walls. Such a situation takes place since when the thickness of the walls is increased, the profile is increased as well, allowing glass fibers to distribute in a random manner, while the thickness of the layer containing glass fibers following the flow direction does not virtually change at all. This particular relation is depicted in Figure 1 [3].

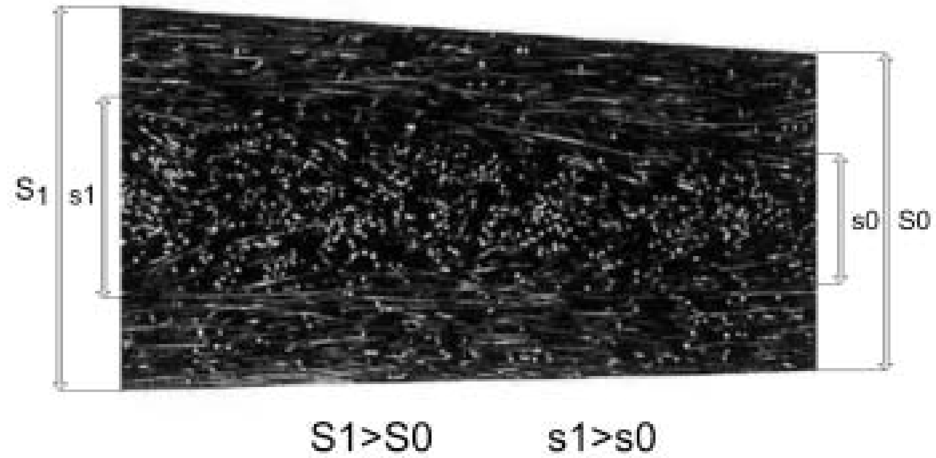

Fig. 1: Orientation of the glass fibers in the core and edge regions S1-s1=So-so

When examining Figure 1, it is not hard to notice that along with the increase in the thickness of the walls, the percentage share of the edge region in the overall wall cross section decreases, while in the case of materials reinforced with glass fibers it is the edge region that determines the overall product rigidity.

3.3. Reinforcement

Since an increase in the thickness of the walls complicates the production process, a designer of a plastic profile may take advantage of additional reinforcement to assure increased rigidity for the target product. In general, maintenance of the appropriate rigidity for designed elements lies in the hands of the designer, equipped with the set of the following parameters:

- increase in the thickness of the walls,
- increase in the Young Module (E) value (e.g. by increasing fiber contents),
- introduction of appropriate ribs in the material.

When examining the case when the rigidity of the final product with a predefined construction was insufficient, a designer ought to at the first step try to utilize another material with the Young Module (E) higher when compared with the input material. An increase in the Young module is relatively simple, since this particular material property depends on the share of the fiber in the polymer. His way, a linear increase in the rigidity can be achieved while maintaining the thickness of the walls unchanged. Another, more effective method for material reinforcing comprises the use of ribs. Thanks to the application of this particular element type, the, the geometric moment of inertia is increased, in the result increasing the overall rigidity of the designed system. When designing reinforcement ribs, it is necessary to consider the optimum rib size, which in turns is determined by the technological, design and aesthetic limitations [1, 3].

3.3.1. Ideal rib dimensions

It is only intuitive that the largest geometric moment of inertia for the given surface can be achieved most easily when using a rib with large dimensions. In the case of thermoplastic materials, such a solution implicates complex problems, resulting in generation of unintentional warping and deformations. Therefore a designer in such a case is always required to examine the rib dimensions in detail, the construction principles of which are depicted in Figure 2.

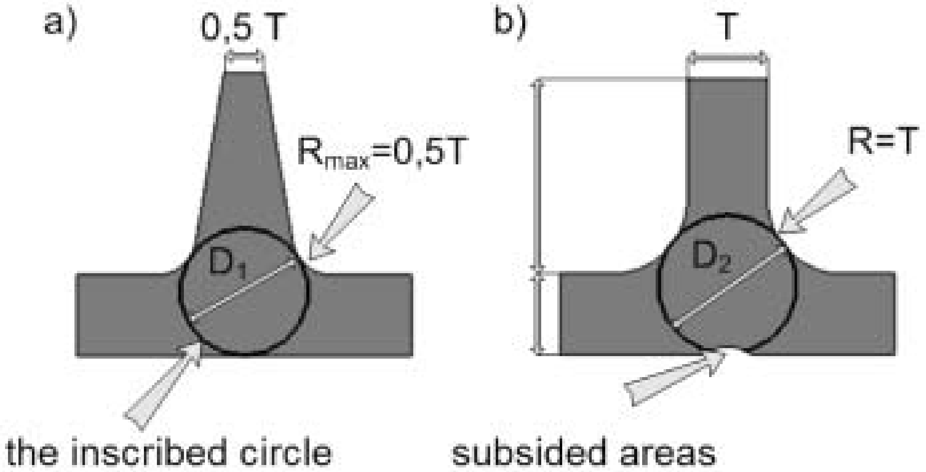

Fig. 2: Rib construction: a) correctly selected rib dimensions, b) poorly selected rib dimensions

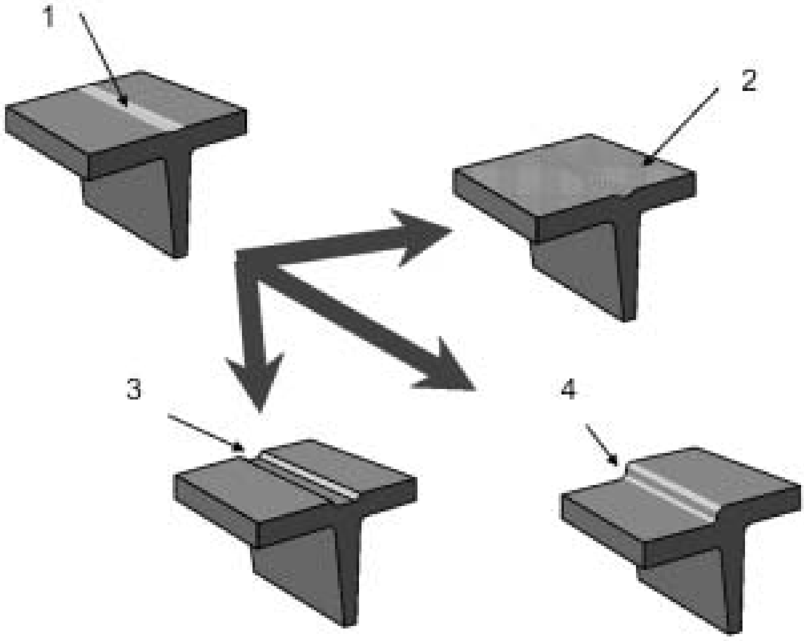

Fig. 3: Leveling the depressions by redesigning or changing surface properties.
1 – depression, 2 – surface patterning, 3 – depression (groove), 4 – surface shift

Properly dimensioned ribs have significant importance in the case of products, which have to be characterized with really large area. It is not only the dimensions of the ribs but also their shape that restrict substantially the tendency of the structure to subside, positively impacting the final product quality. The mass concentration region, occurring typically at the crossing of the mould wall and the rib, is in a general case referred to as the inscribed circle. It is one of the ways to determine the dimensions, allowing the mass concentrations to me minimized, thus resulting in the elimination of the subsided areas or substantial restriction of their occurrence. Figure 2b depicts a variant of the very high mass concentration, resulting in the creation of the so-called contraction cavities, which in turns results in substantial deterioration of the mechanical properties of the designed component.

In some cases, there is no way to match the rib dimensions in such a way that the subsided areas could be eliminated altogether. In such cases, it is typically necessary to redesign the component or change the surface properties in such a way that the resulting subsided area has significantly limited impact on the properties of the molded component. Several possible solutions of this class of problems are depicted in Figure 3 [2, 3].

3.3.2. Decrease in tension at the base of the rib

When designing the ribs, it is necessary to account for the round offs located at the base of the ribs, especially if the product can be subject to significant load by the acting forces. The lack of proper round offs in such an area can cause occurrence of high, mechanical stress, leading quite frequently to the cracks in the designed product. The only means of preventing such problems from occurring in the first place is selecting a sufficiently large radius, providing for appropriate distribution of the mechanical stress at the base of the rib. It is also worth remembering that the too large radii result in aggravated mass concentration problems, leading to the aforementioned problems [3].

4. Material selection

The material used to manufacture the designed pneumatic servo mechanism should first and foremost be sufficiently rigid. Since the said component will be subject to cyclic mechanical stress, it is also worth paying special attention to its mechanical durability. Polyamides are crystalline polymers. The presence of crystalline areas (30-50 %) influences the mechanical resistance to elongation, provides high elasticity modulus, hardness and resistance to abrasion. Simultaneously, the presence of flexible macromolecules in the unordered areas assures good durability and resistance to bending. Moreover, the utilized polyamide provides reasonable balance between the rigidity and durability. It is characterized by good properties under high temperatures and has very good electrical properties, including non-flammability.

5. Application of engineering software for simulation purposes

5.1. General characteristics of the Abaqus software

Abaqus is one of a number of software packages based on the finite element method, designated for the analysis of complex engineering problems. This software allows to carry out virtually any type of simulation, starting from simple linear problems and ending at very complex non-linear simulations, typically representing a significant challenge in terms of design. When designing the pneumatic servo mechanism, it was decided to use the Abaqus software package, since it is already equipped with a very rich library of finite elements, which allow for modeling virtually any target geometry. Similarly, the list of possible material models which can be used in the simulation is also extensive, allowing for precise description on the behavior of not only typical materials used in engineering practice but also other non-standard ones like concrete, rock, soil, plastics, rubber or wood.

One of the basic features distinguishing the Abaqus software from other similar systems is the software architecture, which was designed in a way targeting solution of the non-linear problems. The Abaqus automatically selects the load increments, tolerances and convergence conditions in such a way that the most precise solution can be obtained.

5.2. Durability analysis of the designed pneumatic servo mechanism

Figure 4 depicts two versions of the designed pneumatic servo mechanism. One of them does not have any ribs, while the other one has ribs in the servo mechanism body frame.

Both versions of the designed servo mechanism were analyzed using the Abaqus software. The main emphasis was placed on verification of the deformation of the body frame of the designed servo mechanism, caused by the gas pressure applied to all walls of the examined component. The simulation was carried out for the ambient temperature of 23^{o}C and the humidity of 50 %. Figure 5a depicts the deformation for the servo mechanism with no ribs, equal to 0.37 mm, while Figure 5b depicts the deformation for the servo mechanism equipped the ribs, equal to 0.16 mm on average. This indicates that it is necessary to use a sealing mechanism sufficient to compensate the crack caused by the increased gas pressure.

Fig. 4: The model of the designed pneumatic servo mechanism: 1 – body frame of the servo mechanism with no ribs, 2 – body frame of the servo mechanism with the ribs, 3 – piston rod of the servo mechanism

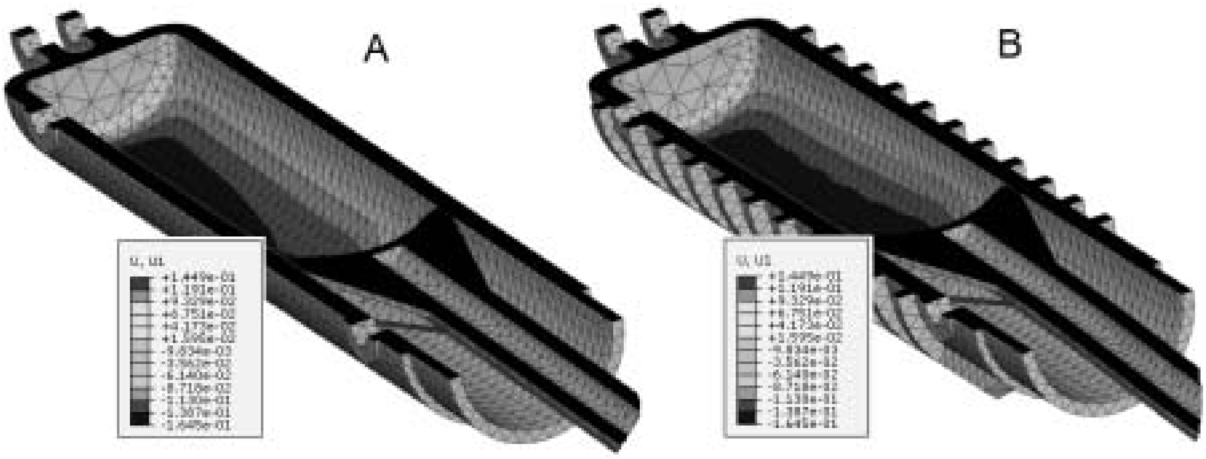

Fig. 5: Deformation: a – servo mechanism with no ribs, b – servo mechanism equipped with ribs

When designing and examining this particular component, it was decided to use PA6 GB20 GF10 material, which is characterized by satisfactory mechanical properties.

Based on the information provided by LANXESS manufacturing the selected polyamide (Figure 6), it can be concluded that the said material can be deformed up to 8 % with the maximum stress of 65 MPa. Assuming high safety coefficient (equal to 2), it can be concluded that the limiting value of the average deformation for the designed component is equal to 4 %. Based on the analysis carried out in the Abaqus system it can be concluded that the average deformation of the body frame of the examined pneumatic servo mechanism under the constant load of 5 MPa would be equal to 2 %, thus fist into the predefined safety range with a significant safety margin.

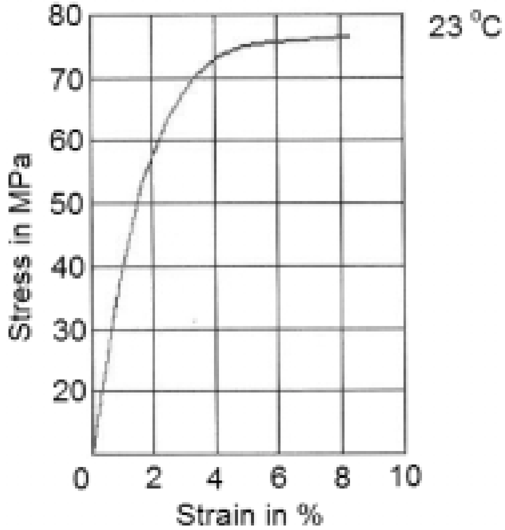

Fig. 6: Relation between the mechanical stress and the deformation for PA GB20 GF10 material manufactured by LANXESS

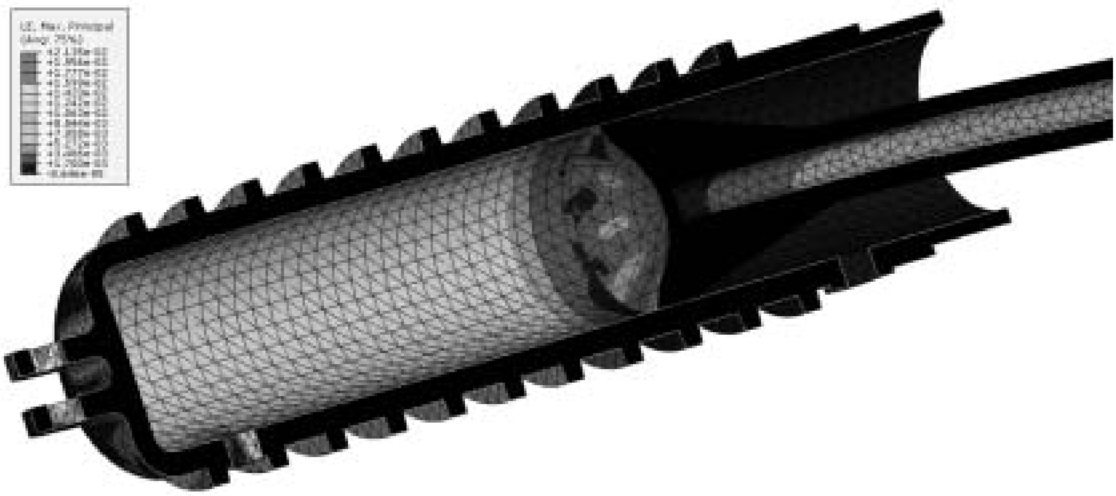

Fig. 7: Average deformation under the target pressure of 5 MPa, exerted at the internal walls of the servo mechanism.

6. Conclusions

This paper elaborates on the process of designing component manufactured from plastic materials with the use of spatial modeling. The presented work targeted creation of a model of a pneumatic servo mechanism along with the elaboration of the necessary analysis aiming at optimization of the construction of this rib-equipped product.

The process of designing components made from plastic materials is substantially complex, where apart from the problem related with the process of modeling the given objects, one has to deal additionally with the proper selection of the target material. The non Newtonian parameters of the plastic flow, varied pressure field as well as different solidification temperatures are just examples of the parameters taken into account by the advanced software packages like Unigraphics or Abaqus. Thanks to the conducted analysis and optimization process of the rib-equipped structure, the designed component was prepared in such a way that the deformation caused by the increased pressure in the servo mechanism chamber does not cause the examined product to unseal.

The techniques based on using numerous simulations at the design stage is under rapid development and represents the next evolutionary step in the design and manufacturing of devices and machinery.

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