Challenges in the designing process of hydraulic cylinders made of plastics

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Abstract.

The use of plastics in the designing of hydraulic components is becoming a new direction in the development of hydraulics. An important example of these course are hydraulic cylinders made of plastics. Previous works of the author presents the process of designing as well as manufacturing and tests of such actuators.
This process was carried out in the following stages: developing of a concept; developing of a design solution and a technological solution; execution of a prototype; computer and experimental research.
On each stage of this process there are challenges, which results from the use of plastics. These challenges differ from those, which are known for the cylinders made of traditional metal materials. Within the article these challenges are stated, propositions of solving them are discussed and some corresponding examples are presented.
Respectively for the stage of concept developing, the rules for selecting the initial technical parameters of the plastic cylinder where set, as well as the rules for selecting the design material and for determining the overall structure of the cylinder. In the stage of developing of the structural solution, special detailed solutions of individual elements are considered. In parallel to the design process, possibilities of the execution of actuator's manufacturing process should be analysed, which aims to obtain the best solution in terms of cost, manufacturing technology and design solution. In the stage of manufacturing of the cylinder, it is of particular importance to obtaining the design features responsible for the technical parameters of the cylinder. Tests of plastic cylinders performed in expanded range are seemed justified, due to the design material which is used. As a preliminary verification, FEM simulation tests are performed. The final verification is carried out through experimental tests, the course of which was determined on the basis of the ISO standard (evaluation of operation correctness and leakages appearance) and extended to tests of efficiency.
The formulation of the challenges is the basis for an effective process of designing hydraulic cylinders made of plastics. As a result, this led to receiving a type of series of such cylinders..

Keywords. hydraulic cylinders, plastics, methodology of design

1. INTRODUCTION

The use of plastics and plastic composites in design of hydraulic components and systems is becoming a new direction on the fluid power. The analysis of the literature shows that a lot of attention is paid to composite cylinders. In works [1, 2] the issue of design and experimental tests of composite cylinders built of carbon fiber and epoxy resin is discussed. In [3] on the other hand, composite cylinder with a multilayer coating is shown, which is characterized by increased strength in relation to the single layer cylinder. The problem of winding and forming of layers on a metal tube is presented in [4]. This knowledge was applied to the design of the composite cylinder [5]. Composite cylinders have lower mass than metal cylinders, they are also durable and can operate under working pressure up to p=20 MPa.

An alternative for composite materials is using of pure plastic materials without composite additives [6]. Prototypes of basic hydraulic elements made of Polyoxymethylene (POM) were presented, which are: gear pump [7], gerotor pump [8], maximum valve and on-off valve [9] as well as cylinder. It was shown that these elements arranged in a hydraulic system are able to operate with the working pressure p = 5 MPa. Particular attention was paid to cylinders made of plastics, for which the design principles and experimental research are presented in [10, 11]. The benefits of using cylinders made of plastics are following:

- cylinders made of plastics, same as composite ones, have lower mass than metal cylinders;
- plastic materials used in their production are cheap and can be recycled;
- cheap manufacturing methods (injection molding) can be used;
- cylinders made of plastics can operate with various working fluids (oil, water) and in aggressive environments.

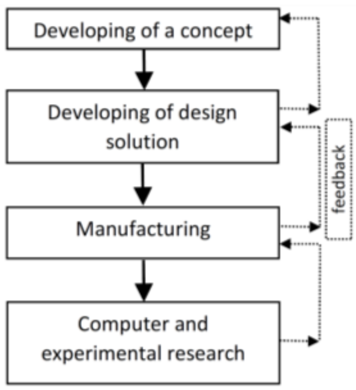


Figure 1.1. Scheme of the process of designing cylinders made of plastics.

After carrying out the process of designing cylinders made of plastics according to scheme shown on fig.1.1, it was found that at each of its stages (concept, design, manufacturing, testing) new challenges arise, which are different from those that occur in case of designing of metal cylinders.

2. CONCEPT

The main challenge that must be met is determination of the general structure of the cylinder and its basic parameters as well as its area of application and operating conditions.

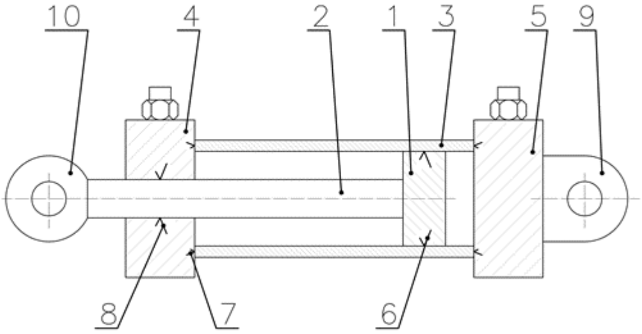


Figure 2.1. Scheme of the basic design concept of cylinder made of plastics.

The general structure of the cylinder is already determined and results from the necessity to implement the principle of reciprocating motion. As shown in Fig. 2.1, it must include a piston (1) with a piston rod (2) that slide inside the cylinder tube (3) to reciprocate. The tube is closed on both sides with cups (4; 5). Because these elements are planned to be made of plastic, which is much more deformable than metal, sealing of individual cylinder nodes becomes a challenge. This applies to the piston seal (6), that cooperates with the cylinder tube (3) which is deforming, the seal between the piston rod and the gland cup (8) and the seal between the tube and the cups (7).

Although plastics are planned to be main materials used in design of cylinders, it should be allowed to use metal for the design material of selected parts that are exposed to the highest loads (stresses). Such approval intends to extend the scope of the cylinders operating parameters, which would be significantly narrowed if only plastics elements would be allowed in design. For example, because of the buckling force, it is advantageous to use metal for the piston rod, thanks to what the entire structure can be loaded with a greater working force. Another example are hydraulic connectors or standard-based mounting parts, which allows the cylinder to be easily installed. However, the share of metal elements should be limited, to enable obtaining biggest advantages of using plastic materials in the structure. To talk about a cylinder made of plastic, it must be the dominant material. Therefore, the share of metal in the structure of the cylinder should not exceed 50% its volume, and the mass of metal parts should not exceed 50% of the mass of its structure. The method of joining metal parts with plastic parts should also be considered.

At the present stage of development, the use of plastic materials, which are less durable than metal, forces limitations for the parameters of cylinders. It is assumed that the cylinders should operate in the range of lower nominal pressures $p_n \leq 6.3$ MPa and maximum (overload) pressures $p_{max} \leq 10$ MPa. The geometrical parameters of cylinders made of plastics should also be narrowed. Plastic cylinder diameters should be less than $d \leq 63$ mm. The possible stroke of plastic cylinders is strongly related to the method of their mounting. It is estimated that the typical method of assembly allows for safe use of cylinders with a stroke $L \leq 250$ mm.

For cylinders made of plastics with a greater stroke, special mounting methods should be provided to increase the stiffness of their structure.

It is also assumed that requirements about life of cylinders made of plastics should be less stringent than for metal cylinders.

It is assumed that cylinders made of plastics could be intended for general applications in low-pressure hydraulic oil systems, where working conditions are not harsh, in particular temperatures are below 50°C.

Plastic cylinders can also be used in water hydraulic systems, which is particularly beneficial for the food, pharmaceutical and medical industries as well for environmental reasons. Cylinders made of plastics can also work in chemically aggressive and corrosive environments as well as environments with electrical voltage.

Finally, the economic and environmental challenges are different. Cylinders made of plastics should be cheap in order to be competitive with metal cylinders. This can be achieved by using cheap, easy available plastics and by adapting methods of manufacturing. An additional positive effect of the use of plastics is that some of them can be recycled and processed many times. As a result of recycling, the same material can therefore be used many times, which reduces costs and environmental pollution.

3. TECHNICAL DESIGN

3.1 Material selection

The fundamental challenge for developing of the technical design is selection of plastic material. The material intended for the design material of the cylinder should meet following criteria:

- mechanical strength (yield point R_e, Young's modulus E) possibly high stability of dimensions which is independent of temperature change (small shrinkage S, small thermal elongation W, low water absorption A);
- possibility to process material by machining and injection molding;
- high availability on the market in form of semi-finished products at the lowest possible price;
- low friction coefficient η in cooperation with seals.

To carry out design work, it is necessary to determine the allowable stresses in the plastic martial. As shown in the strain -stress diagram on fig.3.1, plastic does not have a clear yield point. At the same time, the figure shows that plastics subjected to alternate loading and unloading may not return to its original dimensions, which results from its hysteresis and residual strain. Moreover, fig.3.1 shows that the material strength is connected with the temperature T. Its increase $T_2>T_1$ reduces the strength properties of the material [12, 13]. The mentioned factors should be taken into account while determining the allowable stress level σ_{allow} for plastic material. The easiest way is to assume that the allowable stress σ_{allow} should be equal to the yield stress R_e given by the manufacturer, i.e. $\sigma_{allow}= R_e$.

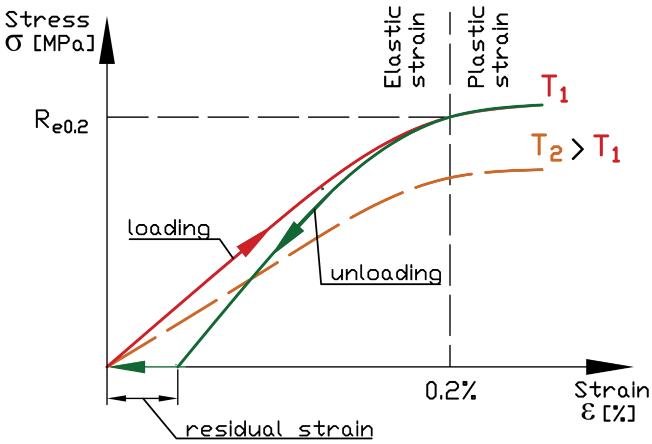


Figure 3.2. Schematic diagram of strain-stress dependences in plastic materials.

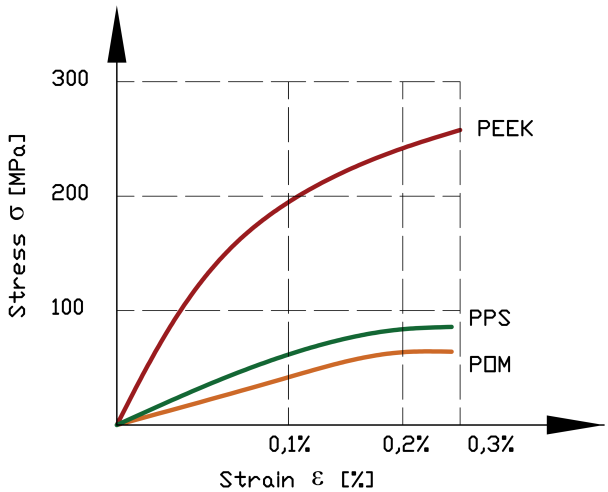


Figure 3.2. Stress-strain diagram for chosen plastic materials: Polyetheretherketone (PEEK), Polyphenylsulfide (PPS) and Polyoxymethylene (POM).

The yield point can also be determined on the basis of own experimental research. The results of such tests for three chosen plastic materials Polyoxymethylene (POM), Polyphenylsulfide (PPS) and Polyetheretherketone (PEEK), are shown in fig. 3.2 in the form of a strain-stress diagram $\sigma=f(\varepsilon)$ [14]. The figure shows that PEEK has the highest strength, then PPS follows, and both are ahead POM in this matter. Own material research confirmed that these plastics do not have a clear yield point. Therefore, the concept of proof stress $R_{0.2}$ was introduced, which is marked with a vertical line in Fig. 3.1. It separates the elastic range of deformations (left side of the diagram) from the plastic one (right side of the diagram). Below proof strength deformations are proportional to loads and it is assumed that after unloading the material does not show significant residual strains. The diagram shows that the strength of the tested plastics does not decrease immediately after exceeding the proof strength. It can be concluded, that under certain conditions, plastics are able to withstand loads that cause stresses higher than those determined by the proof strength. However, above the proof strength behaviour of the material is difficult to predict, because deformations are not proportional to loads. A positive aspect of these observations is that, when allowable stresses are equated with the proof strength, there remain some safety range, within which the material will not be overloaded.

In order to increase the scope of safe use of plastic materials as design materials, it is possible to reduce allowable stress σ_{allow} by applying safety factors according to the dependence $\sigma_{allow}=R_{e0.2}/x$. In this way, the influence of alternate loading and unloading, as well as influence of temperature can also be taken into account.

The determination of allowable stress σ_{allow} is very important for strength calculations and verifying of plastic cylinders by simulations. The method of determining the permissible stresses should be adapted to the operating conditions and the purpose of developing a design solution. For example, if the cylinder is to operate in single work cycles with very long intermissions, and the material is not in contact with high temperatures, then $\sigma_{allow}= R_{e0.2}$ can be applied. In the same way it is recommended to set allowable stresses for prototypes or research models, where determining of the place and nature of possible changes in the structures are one of the reasons of their development. Then, such models and prototypes will better expose these phenomena during operation. If the priority is to develop a structure which is capable to work under high loads in frequently repeated cycles, as well as in contact with temperatures close to 50°C, it is proposed to use safety factors in the range x> 1

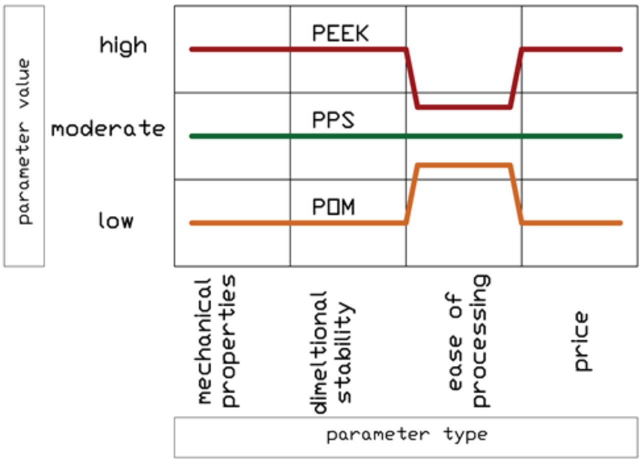


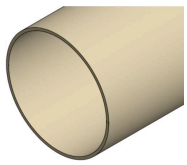
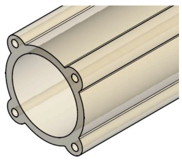
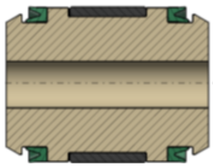
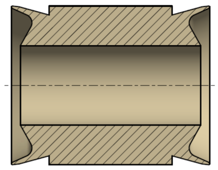
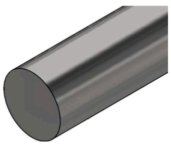
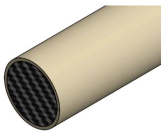
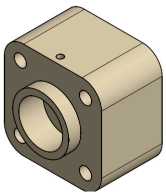
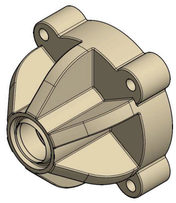
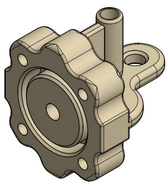
Figure 3.3. Comparison of chosen plastic materials properties: Polyetheretherketone (PEEK), Polyphenylsulfide (PPS) and Polyoxymethylene (POM)

Apart from the strength properties, other properties, which had been signaled at the beginning of this chapter, are considered on fig.3.3. for the selected plastics. Analyzing this scheme it can be noticed again, that PEEK has the best properties, then PPS follows, and both are ahead POM.

However, contrary to these assessments, it is recommended to use POM with sufficient strength and meeting the basic criteria. At the same time POM is easy available and cheap, which is of great importance according to concept assumptions. It is proposed to treat POM as a base material, and any changes for material with higher strength parameters should be made as a development and improvement of verified structures.

3.2 Development of structural design

TABLE 3.1. TABLE OF EXEMPLARY PARTIAL SOLUTIONS CONCEPTS FOR ELABORATION OF STRUCTURAL DESIGNS FOR HYDRAULIC CYLINDERS MADE OF PLASTICS

Name of the part or design node	**Traditional design solutions**	**Progressive (innovative) solutions**
Tube	1.1 	1.2 
Piston	2.1 	2.2 
Piston rod	3.1 	3.2 
Cups	4.1 	4.2 
Mounting	5.1 	5.2 

The general concept of the plastic cylinder formulated in chapter 2 should be transformed into a detailed structural concepts. This is done using table of generating design concepts for cylinder components, table 1. In the table two groups of partial solutions are presented, which are significantly different from each other. These groups have been given names of traditional solutions and progressive (innovative) solutions. In the group of traditional solutions there are:

- cylinder tube made of POM;
- divided piston made of POM assembled with U-shape sealing rings and guide ring;
- piston rod made of a steel rod;
- gland cup and bottom cup made of POM;
- mounting parts, tie rods, hydraulic connectors made of steel and assembled to the plastic cups.

In the group of progressive (innovative) solutions there are:

- cylinder tube with ribs, in which there are bores for tie rods;
- single- solid piston with built-in seals;
- piston rod in the form of a tube filled with a composite material;
- cups with a shape corresponding to the cylinder tube and integrated with the mounting elements.

Of course, it is possible to formulate many solutions of the entire structure through different combinations of presented traditional and progressive solutions, as well as generating completely new concepts of solutions. In summary, the process of developing a structural concepts should be carried out in the following steps: generating partial solutions, synthesis of partial solutions (concerning parts, design nodes and subassemblies) into concepts of entire structures, evaluation of the generated structural concepts and selection of one design for the entire cylinder.

Looking at design presented within traditional solutions, it can be noticed, that they are similar to those used in already proven structures of metal cylinders. However, progressive solutions (1.2- 4.2) are noticeably changed in relation to the metal cylinders. Progressive solutions provide new possibilities, but before their final implementation, additional design and research affords should be made to ensure their appropriate, high technical level, it concerns i.e. of piston integrated with built-in seals (2.2)

Technological and economic reasons do not clearly stand on the side of any solution. Traditional solutions can be realized with the use of prefabricated elements (pipes, rods) or ready seals. Conventional machining can be used to achieve such solutions. It is advantageous in the case of designing of model, prototype or unit production, because using traditional processing methods and universal machines, such as lathes or milling machines, allows for maintaining production costs at a level similar to typical metal elements. Some benefits are possible in terms of machining time, energy requirements and wear rate of the cutting tools because of significantly lower hardness and better machinability of the plastics.

On the other hand, in the case of progressive (innovative) solutions, due to the complex geometric shapes, it would be advisable to manufacture them by injection molding, with use of materials suited to this method. This creates the need to design and manufacture injection molds and high investment costs. Such solutions can be considered competitive when the investment costs are spread over many copies made with the use of the above-mentioned expensive injection molds.

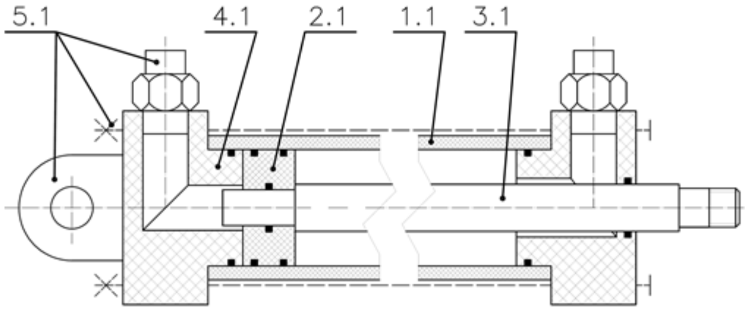


Figure 3.4. Synthesis of partial design solution into one structure of cylinder.

Taking into account presented criteria, a traditional solution was selected for a verification process of design methods of hydraulic cylinders made of plastics, by their implementation through practical application. The reason for such decision was the prototype production scale. Therefore, the subassemblies 1.1- 5.1 were synthesized into one plastic cylinder structure shown in Fig. 3.4.

In the next step, detailed structural design is developed. For this purpose, functional and strength calculations are carried out. Functional calculations concern internal diameter of tube D, piston rod diameter d, speed of piston (rod) movement, force at the end of the rod, etc. Strength calculations concern thickness of tubes wall g, strength of the connections between elements and buckling. The nature of these calculations is considered as quite typical. As a significant innovation may be recognized the use of previously specified allowable stress, which is determined according to the guidelines presented in chapter 3 section 3.1.

As a result of meeting design challenges and synthesizing partial solutions into design solution of whole structure, a plastic cylinder is created.

4. MANUFACTURING

The production of plastic elements of hydraulic cylinders is a serious challenge in the design process and an important stage in the verification of the adopted design assumptions. Thanks to the obtaining of the real object, verification can be carried out in relation to:

- design process correctness
- correctness of standardized parts selection
- manufacturing technology adopted for non-standard parts
- manufacturing quality of parts

There are two basic methods of manufacturing cylinders made of plastics, which are the machining method and the injection molding method.

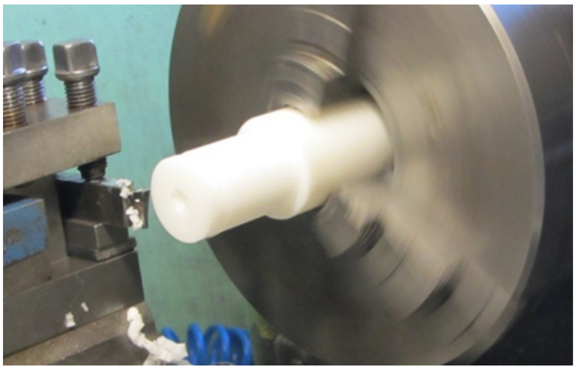


Figure 4.1. Manufacturing of the piston made of plastic (POM) by machining on lathe.

The machining method is more advantageous in the case of small-scale, unit or even prototype production. Cheap and easily available semi-finished products can be used in these method, offered in various dimensional versions in the form of pipes, plates, blocks or rods. The semi-products are machined to obtain the final part geometry. The selection of the appropriate dimensional version and the correct shape of the semi-products for specific parts, allows for reducing of the number of machining operations and shortening of the production time. Example of manufacturing of the piston from plastic (POM) rod by machining on lathe is shown in fig. 4.1. With the use of machining, technological challenges arise. Plastic materials behave slightly different than metals when machined. Typical is a slight deformation (deflection) of the material under the pressure of the tool, as well as change in the dimensions of the material under the influence of heat generated during machining. Due to these phenomena, the manufacturer may not be able to obtain the correct precision on the first attempt. Therefore, it is good practice to perform trial machining operations and adjust the machining parameters to the behavior of the material during its course. Material samples for such trial operations should be provided.

In case of the injection molding method, the plastic elements of the cylinders are shaped in the molds by pressing into them plastic in a liquid form and then solidifying. Therefore, precision of the manufactured elements depends on precision of the molds, the shape of which plastic material acquires. In the process of designing molds, many factors must be taken into account, such as the way the material flow, the speed of solidification of the material, etc. The production of precise injection molds is time-consuming and costly. This makes it a separate issue that requires a lot of specialized knowledge and experience. The injection molded parts themselves should also be designed specifically for this method, e.g. walls of the parts should have low thickness. Thanks to this method, however, any shape can be relatively obtained, which allows to gain large design advantages, which cannot be achieved in cylinders made of metal or some composites.

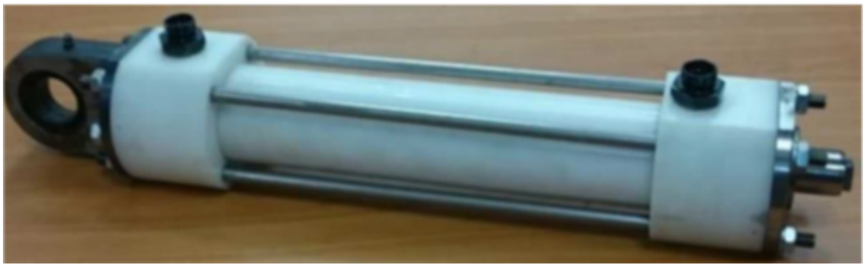


Figure 4.2. Manufacturing of the piston made of plastic (POM) by machining on lathe.

Using the first method, a prototype cylinder of internal diameter Ø=50 mm was made of POM.. Prototype is shown in Fig.4.2. A very important stage of the process is precise machining of the inner surface of the cylinders tube. The process should ensure the precision of the diameter dimension +0.075mm; circularity of the hole up to 0.05 mm; straightness along the tube axis 0.1 mm and surface roughness as specified by the manufacturer of the seals, usually within the limits R_a<0.3. In addition, to ensure the long life of the seal, the key is to obtain right direction of the machining marks, which should be arranged along the axis of the cylinder. It is recommended to do this by preparing special tools, which allows for material cutting in the axial direction, as well as positioning the tube vertically during machining.

5. VERIFICATION- COMPUTER AND EXPERIMENTAL RESEARCH

5.1 Computer Finith Element Method simulations

Because cylinder is made of plastic materials, the strength of which is lower than that of metals, the nature and values of stresses and strains in its structure should be examined.

This challenge is realized with the use of Finite Element Method. Because of the fact, that a computer is used for the FEM simulation, it can be carried out in parallel or before the cylinder manufacturing stage. In the algorithm, however, the simulation stage has been placed in the way that clearly indicate the connection between this stage and the verification of a specific structure developed at the design stage. The geometrical model is therefore developed on the basis of the adopted structural design solution (cylinder Ø50 in Fig. 3.4).

It is assumed that the selected plastic material will work in the range of elastic stresses, below the allowable values set by the constructor on the basis of the guidelines discussed in chapter 3 section 3.1.

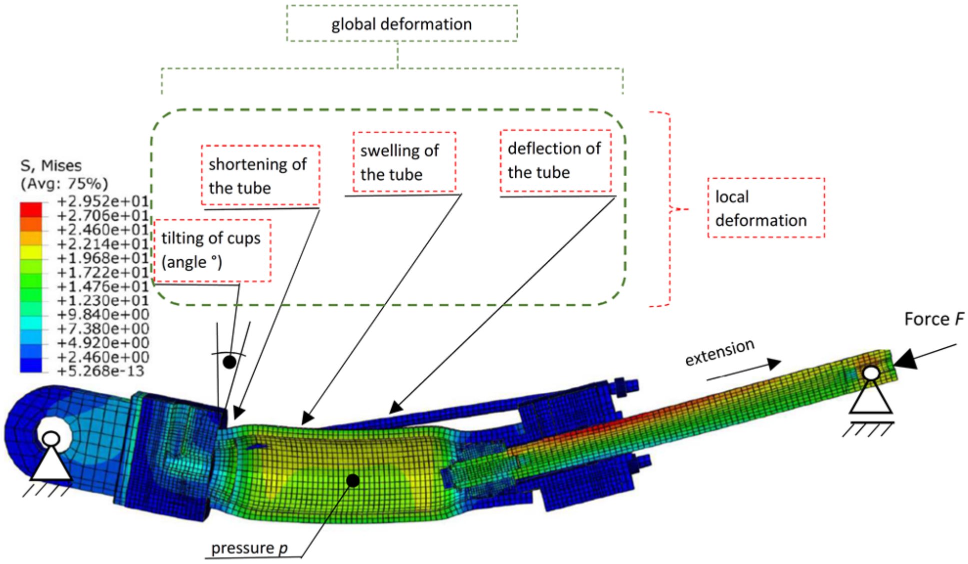


Figure 5.1. Schematic description of deformation in the structure of cylinder made of plastics, which is fixed in the bottom cup and at the end of piston rod.

On fig.5.1 the mechanism of the formation of plastic cylinder deformations is analyzed. The cylinder is fixed in the bottom cover and at the end of the piston rod, which corresponds to the often used method of mounting in machines and devices. At the same time, it is the most unfavorable way of fixing the cylinder. During the extension, under the load of pressure p and force F, the so-called local deformation of the cylinder subassemblies appears, i.e. tilting of the cups as well as swelling, shortening and deflection of the tube. The combination of local deformations results in global deformations of the actuator, in which the deflection and swelling of the actuator are decisive. Their value depends on the material, geometry (e.g. length, diameter, wall thickness) and loads (pressure p and force F).

By analyzing local deformations, behavior of the cylinder during operating can be predicted. Swelling of the cylinder tube walls and a change of its internal diameter can cause internal leakage and decrease of efficiency. This can be prevented by selecting seals which are able to adapt and compensate for changes in inside diameter. Strains analysis allow for prediction of the risk of cylinder buckling. The image of cylinder deformation with the extended piston rod indicates on a clear buckling. Such interpretation supplement the classic buckling calculations.

Apart strain maps, also stress maps in the cylinders elements are obtained. As a standard, their result and values are analyzed and compared with the allowable stresses, which are set by the constructor for the selected plastic material used to for the cylinder. Exceeding the allowable stress is a signal to redesign the overloaded cylinders subassembly or cylinders element.

5.2 Experimental research

The final challenge in the process of designing hydraulic cylinders made of plastics is experimental research, which determines definite judgement about the correctness of structural design of the cylinder and its work.

In the case of metal cylinders, tests according to the ISO 10100:2001 standard are carried out, which cylinder must pass in order to be allow to use. They consist of test for leakage at low pressure p_{min}, piston seal leakage test at p_{nom}, and proof/external leakage test at overload pressure p_{max}. These tests are also performed for plastic cylinders, but in the case of such significant differences in design materials, there is a need for verification in a wider scope. Therefore, additional trails are recommended, where tested are:

- piston rod movement speed during extension and retraction, without and under load
- influence of using plastic material on achieved technical parameters
- ability to long-term operating
- behavior of structures of cylinders made of plastics under load (global deformations)

The constant speed of extension and retraction as well as high efficiency, prove the correct cooperation of the piston with the tube and the piston rod with the gland cup. It also indicates that movement resistances in these design nodes are low. Low resistances of motion are also information that the structure remains stable and there are no significant transverse forces that could lead to increase of such resistances. At the same time, the high efficiency of the cylinder indicates that there is no internal leakage between bottom chamber (under-piston chamber) and gland chamber (over-piston chamber).

Tests of long-term operation, depending on the research capabilities and assumptions on working conditions of the cylinder, may cover the range from 1000 to 1000,000 cycles under load. As a result of its condition, it is possible to determine the life of plastic cylinders, but most of all, it confirms the ability to repeat the cycle of work many times, therefore, eventual suitability for actual use in mechanical systems. It should be taken into account, that plastic cylinders will not be able to last the same long period of operation as metal cylinders. However, this does not disqualify plastic cylinders, as it is assumed that they should operate in a shorter life period and with less work intensity.

A special challenge is experimental research of deformation of cylinders made of plastics. Various test methods can be used to determine deformation, such as strain gauge method, tests with displacement transducers or optical research based on image analysis. The accuracy of the obtained results may depend of the chosen method. However, neither method should be negated because hydraulic cylinders made of plastics are new technical objects. Characteristic aspect of such new technical objects is small amount of information about behavior of their structures. Moreover, the hysteresis of the strength parameters of plastic materials is the reason why their behavior as design materials remains unexplored. Research on the behavior of structures of cylinders made of plastics is therefore of great importance, both in relation to the methods of designing such objects, and the plastics themselves as design materials. Even examining the very nature of deformations without establishing precise values may be important in the context of optimization.

Examples of test results for cylinder deformation are shown in Fig. 5.2. Fig. 5.2. a shows the global displacements measured on the surface of the cylinders tube along its length. Fig. 5.2. b shows schematically the deformed tube superposed on the background of the non-deformed tube. Both figures show that the displacement along the entire length of the tube has positive values. This means that deformation of the tube walls caused by its swelling is greater than its deflection, and consequently the global displacements are positive.

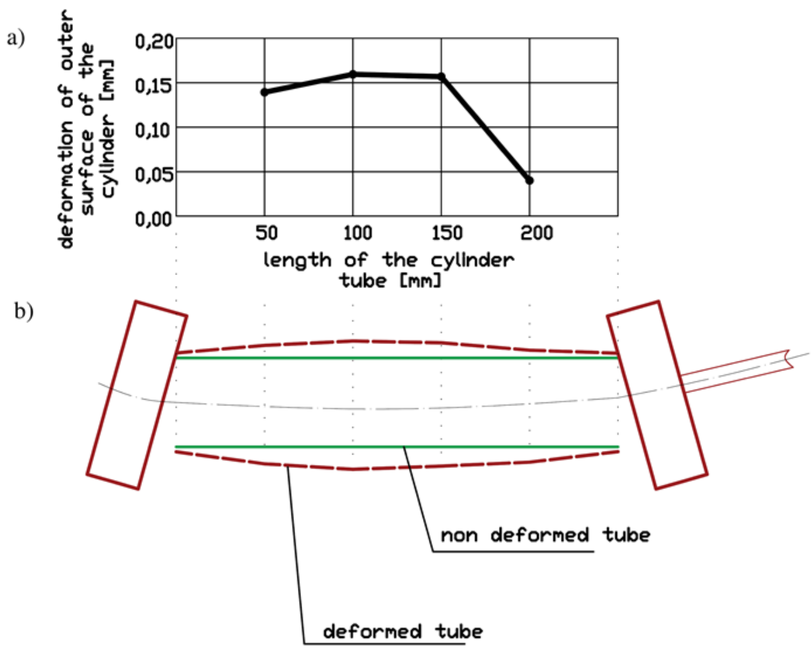


Figure 5.2. Results of tests of deformation performed for prototype of hydraulic cylinder made of plastic: a) values of deformation (displacement) of the other surface of tube; b) schematic representation of global deformation of the prototype.

6. CONCLUSIONS

The use of plastic in the designing of hydraulic cylinders creates new challenges at every stage of the process.

The fundamental challenge is selection of material which has an impact on design, technology, operation and application area. Plastic has lower strength and dimensional stability than metal. Pulsation of loads and an increase of temperature causes decrease of strength, as well as dimensions changes of the plastic parts of the cylinder. Therefore, plastic hydraulic cylinders should have a narrowed range of geometric dimensions (diameter $d < 63$ mm and stroke $S < 250$) and work with lower nominal operating pressure values ($p < 6.3$ MPa) compared to metal cylinders. It is likely that these limitations will decrease, and recommended ranges will become wider with development of cylinders made of plastics. Therefore, the issue of the selection of plastic for design material should not remain a closed area, but it should be updated and supplemented.

The choice of plastic for design material cause arising of design challenges, which are also opportunities for new, innovative design solutions. This applies, among others, to pistons and cups with built-in seals, cups integrated with mounting elements (reducing the number of parts), ribbing of cups and cylinder tubes (increasing the stiffness of the structure).

The use of plastic creates challenges connected with manufacturing. In case of machining, the challenge is to determine machining parameters and adapt machining methods. An example could be a cylinder tube. For the correct cooperation of the sleeve with the piston seal, it is crucial to obtain a high-quality inner surface of tube and an appropriate orientation of the machining marks. The greater is stroke of the cylinder, the greater is length of the sleeve and the more difficult it is to ensure accuracy. From the other hand, the injection molding method can be expensive due to the need to making the molds

The life of cylinders made of plastics is also a serious challenge. This life may be shorter than that of metal cylinders. At the same time, however, there are aspects encouraging the development of plastic cylinders, such as: lower mass, resistance to aggressive conditions or the ability to work with various working media, including water and chemical liquids, as well as the chance to achieve low costs in production on large-scale .

Finally, many plastics can be recycled, which is very beneficial given the increasing importance of environmental protection.

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