Issues of a Computer-Aided Design of Hydraulic Jacks

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Abstract. The article deals with the issues of a computer-aided design of hydraulic equipment, namely hydraulic jacks. Design principles of the hydraulic jack CAD system are described. In addition, the possibilities for the system improvement and expansion are considered.

1. Introduction.

Designing hydraulic equipment, namely hydraulic jacks, is a difficult and time-consuming task requiring broad experience of design engineers in the sphere of hydraulic equipment design and production and cooperative effort of a team of engineers, which is extremely impracticable for small enterprises [4].

Although most small enterprises employ CAD systems for jack design, these systems are only used for 3D modeling and preparing design documentation, all the rest is done by engineers without using automated systems [5].

That is why it is essential to develop systems making the whole jack designing process automated.

For automatic implementation of fully or partially formalized tasks it is not at all difficult to create a software aimed at solving not only design preproduction problems but in some cases the problems of manufacturing preparation [2, 6].

2. CAD Principles for Hydraulic Jacks Design

A hydraulic Jacks CAD system simplifies engineer’s work. The system provides for calculation of hydraulic jack parameters and automatic construction of 3D model, creation of associative drawings and other required documentation on its basis [2, 4, 10].

When developing the hydraulic jacks CAD system a collaborative analysis of requirements and design was carried out:

\[ D = \langle Zi, Ij, Pk, Hn, Ms \rangle \] (Figure 1).

Let us consider an example: \( D = < \text{machine tool building, spring return, 5…10 ton, 50…100 mm, steel}> \), these requirements are met by several types of jacks, so they are ranked against three criteria: cost, production time and service life.

The developed CAD system is a software product capable of performing a part of the design algorithm independently of other software such as a basic system of geometric modeling used for creating 3D models of parts and hydraulic jack assembly.
Keeping in mind the structure of the hydraulic jack several variants of its assembly units were specified: a connection point of the bearing box and barrel, a piston and a rod, a rod guide ring, a scraper, a spring assembly, a unit for power fluid supply and a portable unit.

The analyzed principal models of jacks being designed can be represented by the system:

\[ D = \{Bbg, Ppsh, Nnsh, Ggr, Hpr, Lr, Rtr\}, \]

where

- **Bbg** – a set of decisions of the bearing box attached to the rod;
- **Ppsh** – a set of decisions for the piston and rod assembly;
- **Nnsh** – a number of rod way models;
- **Ggr** - a number of scraper models;
- **Hpr** – a set of decisions for the spring assembly;
- **Lr** – a number of variants of the power fluid supply;
- **Rtr** – a number of ways of jack transportation.

From the set of hydraulic jack components containing a set of decisions one assembly variant for each unit is chosen according to the technical specification. This enables the determination of the final arrangement of the hydraulic jack.

Each element in the design scheme has several design solutions, which are stored in the database in the form of parameter-oriented models. A final decision is made on the basis of the construction design.

Having studied the possible solutions in the hydraulic jack CAD system 8 possible modules were developed:

- a module of calculating the basic jack parameters;
- a module of selecting the sealing;
- a module of bearing box calculation;
- a module of piston calculation;
- a module of spring calculation;
- a module of spring locators calculation;
- a module of cylinder tube calculation;
- a module of calculation of standard jack components [1].

In the module of seal selecting, the program gives the engineer a choice of seals suitable for this design; this option gives the engineer a possibility to program the seals which are available (Figure 2).
For illustrative purposes when selecting from the available seals the principle parameters are shown. After selecting all suitable seals the engineer proceeds with the calculation of jack principle components. All principle jack components — a bearing box, a piston, a spring, a barrel, a bottom, fixtures and springs — are calculated (Figure 3).

After calculating all principle jack components the engineer is offered to create a 3D assembly model of the jack and all its components; using the model it is possible to make assembly drawings of the jack and all its components. Also the program helps the engineer to make a report containing all calculation parameters and to prepare a datasheet of the obtained jack.

When developing the CAD system mathematical support for the hydraulic jack design the following calculation algorithms were carried out:

- overall calculation of the hydraulic jack main geometric parameters;
- calculation of the bearing box geometry;
- piston geometry calculation;
- suitable seal selection;
- spring selection and its geometry calculation;
- spring locators geometry calculation;
- barrel geometry calculation and, if possible, selecting a suitable workpiece;
- male and female metric thread parameters calculation;
- selecting parameters of male and female threading relief grooves;
- engineering calculation of thread shear and collapse of screw fillet, etcetera [1].

One of the modules of the hydraulic jack CAD system is a module of calculation of hydraulic jack main geometric parameters.
At the first stage the piston diameters are calculated using the formula (1).

\[ D = 2 \cdot \sqrt{\frac{p}{\pi \eta m (P_c - P_h) \Psi}} \]  

(1)

where \( D \) – jack piston diameter (mm);
\( P \) – rod force (N);
\( \eta m \) – jack mechanical efficiency, which is in the range of 0.93–0.97 and depends on the jack diameter and the type of sealing;
\( P_c \) – rod end pressure (Pa);
\( P_h \) – rod end pressure (Pa);
\( \Psi \) – intensifier ratio.

The calculated value of piston diameter \( D \) is rounded up to the nearest whole number according to GOST 12447-80 (Table 1).

Table 1. Jack piston diameter values regulated by GOST 12447-80.

| Main variety, mm | 10, 16, 20, 25, 32, 40, 50, 65, 80, 100, 125, 160, 200, 250, 320, 400, 500, 630, 800 |
|------------------|-------------------------------------------------------------------------------------------------|
| Additional variety, mm | 14, 18, 22, 28, 36, 45, 50, 70, 90, 110, 140, 180, 220, 360, 450, 560, 710, 930 |

Jack rod diameter \( d \) is calculated using the formula (2):

\[ d = D \cdot \sqrt{1 - \frac{1}{\Psi}} \]  

(2)

The value of rod diameter \( d \) is rounded up to the nearest whole number according to GOST 12447-80. Having the values of the piston and the rod we can calculate the jack wall thickness using formula (3):

\[ \delta = \frac{D}{2} \cdot \frac{[\sigma] + Py(1 - 2\mu)}{[\sigma] - Py(1 - 2\mu)} - 1 \cdot n. \]  

(3)

where \( \delta \) – jack wall thickness;
\( [\sigma] \) – yield point;
\( Py \) – nominal pressure equal to 1.3\(* P \);
\( \mu \) – Poisson’s ratio;
\( n \) – strength factor.

The values of \( [\sigma] \) and \( \mu \) depend on a cylinder material [4].

One of the most resource-intensive algorithms is the algorithm of selecting the extension spring (Figure 4). This algorithm is based on the extension spring calculation method; the suggested approach reduces the spring assembly design time by several times.

The algorithm starting point is determining a spring type. Then the database is addressed and suitable springs are built into an array.

Then the user selects a suitable spring on the basis of the empiric data and calculates the spring working deformation strain.

The next stage is calculation of the number of spring coils. First, the number of active spring coils is calculated and an inspection is carried out. Based on the inspection results either an inability message of calculating active spring coils is produced or a transition to the next stage is made.
If calculation of the number of active spring coils is a success, the calculation of the total number of spring coils is carried out and its accuracy is then verified. If the total coils number was successfully calculated, a transition to the next stage is made; otherwise calculation inability message is produced.

The next stage is spring force calculation and after that a verification of its results is performed. If spring force was successfully calculated, a transition to the next stage is made; otherwise spring force calculation inability message is produced.
After that calculation of spring deformations and length with a subsequent verification of results is carried out. If calculation was not performed successfully, a spring deformation calculation inability message is produced; otherwise a transition to the next stage is made.

The final stage of spring calculation is calculation of spring prestrain and force. If this calculation is not a success, an error message is produced, otherwise the spring is considered to be designed.

3. Changes to the Design Process of Hydraulic Jacks after CAD Implementation.
Before the development and implementation of the hydraulic jacks CAD system design engineers used CAD merely for preparing the design documentation. The algorithm of jack parameters calculation was performed manually using a great number of standards, recommendations and catalogues of standard articles (Figure 5).

The design engineer had to manually calculate a great number of parameters, many of which were to be then selected from the standards.
After implementing the hydraulic jacks CAD system all these calculations and all data handling are performed purely by the CAD system and one design engineer is able to operate it, responding to its questions and finalizing the design documentation (Figure 6).

4. Results and Further Development
Nowadays the developed CAD system for designing hydraulic jacks with spring return has been tested within the actual projects in the small enterprise and is ready for implementation in other enterprises and further expansion.

The improvement of the hydraulic jack CAD system includes adding new modules of hydraulic jack parameters calculation. This will enable widening of a product range of hydraulic jacks.

Later it is planned to improve the program functionality by adding new types of hydraulic equipment such as a pumped storage plant. At present all calculations necessary for its design have already been structured, and a necessary amount of parameter-oriented models of components of the pumped storage plant have been prepared.

In the process of automation of the pumped storage plant design it is planned to develop the following: a pumped storage plant calculation technique, a library of the main geometric elements of the plant and a selection algorithm of the optimal plant design.

5. Conclusion
When developing the CAD system all its stages were thoroughly elaborated beginning with its technical specification and finishing with its testing and implementation.

The developed CAD system enables the reduction of jacks design time, the period of design documentation preparation as well as other design process costs.

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