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COMPUTER APPLICATION IN HYDROSTATIC TRANSMISSION TECHNOLOGY

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Abstract: *Hydrostatic transmission technology must achieve some goals in order to ensure its continued progress and growth, to preserve current position in the market and to compete efficiently with other energy transfer technologies (mechanical and electrical). In a specific way, activities for achieving the goals imply computer application. The paper gives a few examples of how computers are today applied in modern hydrostatic transmission technology. They are used in control and data analysis, condition monitoring, design & modelling of components and complete transmission, and even marketing & e-commerce.*

Keywords*: hydrostatic transmission, computers, control, condition monitoring, design & modelling*

1. INTRODUCTION

Today, it is hard to imagine any modern transport system or production process without hydrostatic drives. Other applications include earthmoving, construction, aerospace and agricultural machinery industries. The primary function of any hydrostatic transmission (HST) is to accept rotary power from a prime mover (usually an internal combustion engine) and to transmit that energy to a load. The HST generally must regulate speed, torque, power, or, in some cases, direction of rotation of a load.

Compared to other forms of power transmission (mechanical, electrical) HSTs offer many important advantages. Depending on its configuration, an HST:

- transmits high power in a compact size,
- operates efficiently over a wide range of torque-to-speed ratios,
- has low inertia,
- maintains desired control speed (even in reverse direction) regardless of load, within design limits,
- maintains a preset speed accurately against driving or braking loads,
- can remain stalled and undamaged under full load at low power loss,
- can transmit power from a single prime mover to several locations, even if position and orientation of the locations changes,
- does not creep at zero speed
- provides more rapidly response than mechanical or electromechanical transmissions of comparable rating, and
- is able to provide dynamic braking.

In present days, the HST industry has relatively substantial and stable position in the world market. USA, as the one of the richest and the most prosperous economies in the world, is a global leader in manufacturing and selling of the products. In USA alone, the revenue of fluid power pump and motor industry was approximately $ 4 billion in 2006. Over the last decades fluid power hydraulics was exposed to strong competition from other means of transmitting power. In order to retain current market position, hydrostatic transmission technology must achieve some goals, in order to ensure its continued progress and growth, preserve current position in the market and compete efficiently with other energy transfer technologies. These goals can be categorized in seven areas of activities as follows:

- energy conservation,
- leakage control,
- fluid stability control,
- proactive maintenance,
- contamination control,
- microcomputer control, and
- computer aided engineering [1].

HST technology must integrate (directly or indirectly) computer technology for easier achievement of all these goals.

2. MICROCOMPUTERS IN CONTROL AND IN DATA ANALYSIS

One of the most significant contributions of microcomputer's applications in HST technology is the opportunity that it offers to implement sophisticated control and data analysis algorithms on the computer. Since the latest 1940's, fluid power researchers have tried to create a technology that should integrate fluid power "muscles" with the electronic "brain" [2]. Different control strategies were developed and implemented in HST systems in order to achieve this task. Most of the publications related to the HST control are addressed to controlling the speed of end-user(s). And this, despite the fact that there is a considerable number of applications that include position and force control systems. Different closed-loop control strategies have been used in order to achieve these goals. Classical control approaches are very much standard practice in the industry nowadays [3], [4].

Recent advances in the area of control theory involve non-linear “classical” and intelligent control techniques (predictive control, adaptive control, fuzzy control, neural nets, genetic algorithms, etc). It is expected that smarter and more responsive control strategy will be used more in the future [5].

There are few examples of application of new-sophisticated HST control systems. Here are briefly specified some of them: self-tuning adaptive control (a controller combines parameter estimation and the technique of pole-placement) [6], Linear Quadratic Gaussian design method for a speed control of a vehicle drive HST system [7], nonlinear optimal control of a HST with variable-displacement pump and motor [8], H_∞ robust control to regulate speed of HST [9], discrete-time robust controller design methodology applied for the variable displacement hydraulic motor-driven trimmable horizontal stabilizer actuator in aircraft systems [10], Neural Network control system for precise angular position control system of the hydraulic rotary actuator [11] and many others. It should be emphasized that these artificial intelligence control techniques are still not robust enough to provide the required level of safety, thus there are not many implementations of these control techniques in industrial applications in which the safety is critical.

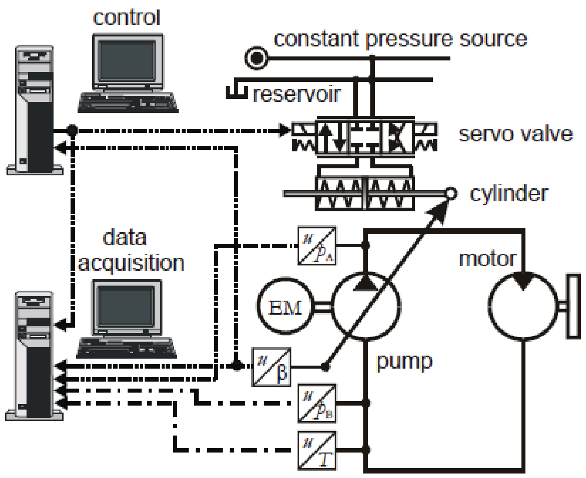


Fig. 1. The example of measurement setup for parameter identification of HST [4]

The use of microcomputers for data acquisition and parameter identification has been overwhelming in most fluid power laboratories. The major function of the microcomputer tends to be nothing but a monitor for multiple sensors and a data logger. Very popular software for such purpose is LabView. The current trend is in extending microcomputers use to do diagnosis and troubleshooting, which are both parts of real time condition control. The kernel of diagnosis and troubleshooting is to have an inference engine, which can analyse and interpret data acquired from the system. Model based condition monitoring is a method to detect failures by using a simulation model. Measuring results of the system are compared to simulation results of undamaged system (fig. 2). If differences are found, the system determines the character of the failure using microcomputers [12]. It has been found that neural network can be used for fault detection of fluid power system for its proactive condition monitoring system [13].

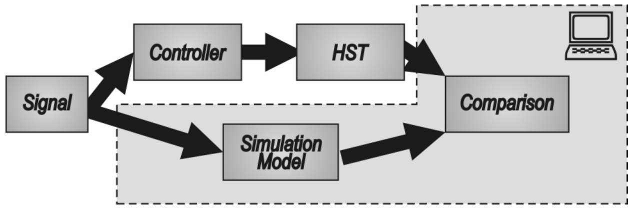


Fig. 2. The concept of model based condition monitoring of HST

3. PERSONAL COMPUTERS IN DESIGN

Two different design approaches in HST technology can be distinguished. The first is associated with the design of HST components and the second with the design of HST systems. Although these two design approaches are basically different they are strongly correlated.

HST component design

For a simple fluid power component, a designer may be able to accomplish component design task using a trial and error approach or his experience. However, if it is a relatively complex component, such as pump or motor, the task becomes more difficult. In order to tackle today's highly demanding applications, an engineer must have more powerful tools. It is totally unacceptable from a cost standpoint to permit the design factors of hydraulic components to be estimated and then fabricate the components to see if they work. The best tool available is the personal computer with an effective software packages.

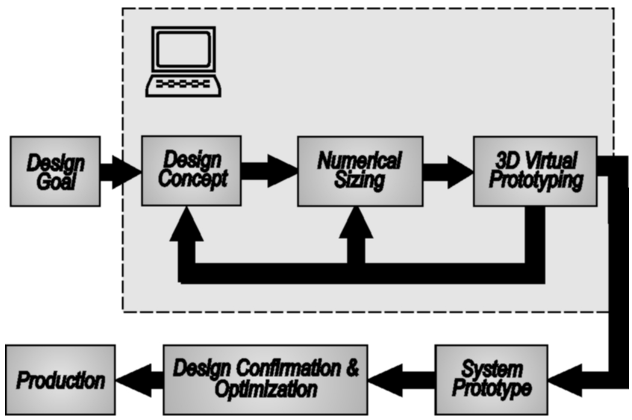
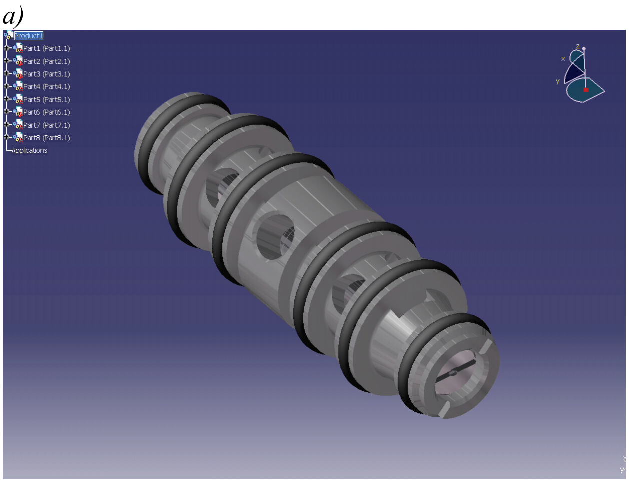


Fig. 3. HST component design procedure

A contemporary approach to computer-aided design of HST components should pursue procedure of 3D virtual prototyping shown in fig. 3. Using parameters defined in design goal, component designer choose design concept and implement fluid power design principles onto the PC, in order to develop appropriate numerical model for calculating component dimensions. She/he writes original software using one of common programming languages (C, C++, Fortran, Visual Basic, Pascal, Java, etc.) or uses a design software package (like MathCAD, Maple, Mathematica, etc. or even spreadsheet program like Microsoft Excel). Results of numerical sizing calculations are often exported to external database file, with a format recognizable by some CAD software, such as (CATIA, Solid Works, Mechanical Desktop, Inventor, PRO/Engineer, etc.). Previously, a design engineer drew parametric 3D presentation of designed fluid power component in CAD software. The software interprets data of numerical calculation and then generates 3D virtual prototype of fluid power component. It is easy to obtain complete design documentation from this virtual prototype or even complete technological procedure for manufacturing segments or even whole component. Results of 3D virtual prototyping performed at Department of Energetic and process engineering Faculty of Mechanical Engineering Kragujevac, for several HST components are shown in fig. 4. Correct virtual prototype enables manufacturer to construct physical component prototype that can go to production, after the positive evaluation period through laboratory tests.

a)



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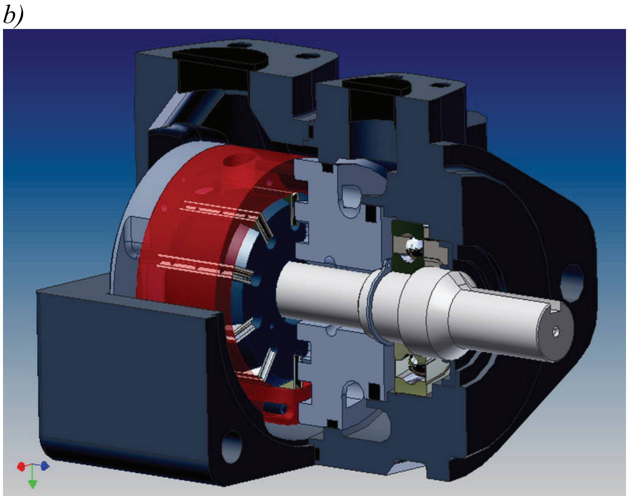
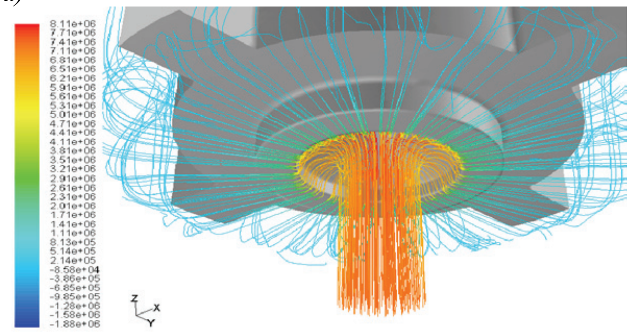


Fig. 4. Examples of 3D virtual prototyping performed with different CAD software
a) spool and sleeve – CATIA, b) hydraulically balanced vane pump - Inventor

Application of CFD (Computational Fluid Dynamics) method can significantly improve component design, because it creates possibilities for extensive exploration. It offers the effortless, but also inexpensive way of estimation and examination of relevant flow performance of an arbitrary fluid power component. It eliminates the requirement for expensive experiments that often have uncertain results. With systematic interpretation of CFD results, more precise values of parameters that are used in component design are obtained. There are a lot of commercial software for CFD on the market and the most predominant are Fluent, Star-CD, CFX, Phoenix, etc. Examples of CFD applications in fluid power are numerous and some of them can be found in references [14] – [18].

a)



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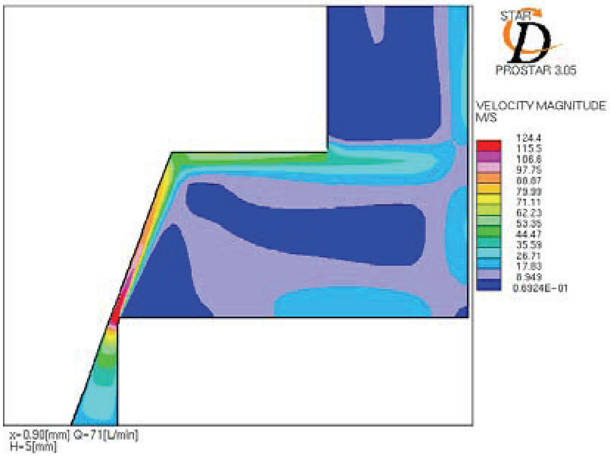

Fig. 5. Examples of CFD application
a) pressure path lines over flat poppet - Fluent [14],
b) velocity profile in hydraulic seat valves – Star-CD[15]

HST system design

Generalized HST system design process is illustrated in fig. 6. From design goals, a design concept to be integrated into the system must be established and a system schematic must be developed, along with the operational specifications for the system [19]. Once these tasks are completed, a designer will enter into the component sizing and selection process. The common belief is that fluid power technology is "simple" and, hence, one does not need to be a specialist in order to apply it. Thus, anyone with an elementary knowledge of mechanical engineering feels that she/he can design and build a system using off the shelf components selected from catalogues provided by manufacturers and only some elementary calculations of powers, flows and pressures. In most cases simple system, designed this way, will perform in some fashion, not necessarily optimally. In the past, when the sizing and selection phase was completed, components would be purchased and a prototype system constructed. The system performance was not simulated and the success of a particular system was mainly the result of designer's experience and luck. Actual performance characteristics were evaluated through laboratory and field tests using the system prototype. Optimisation was a function of a process, which was normally called “cut and try”.

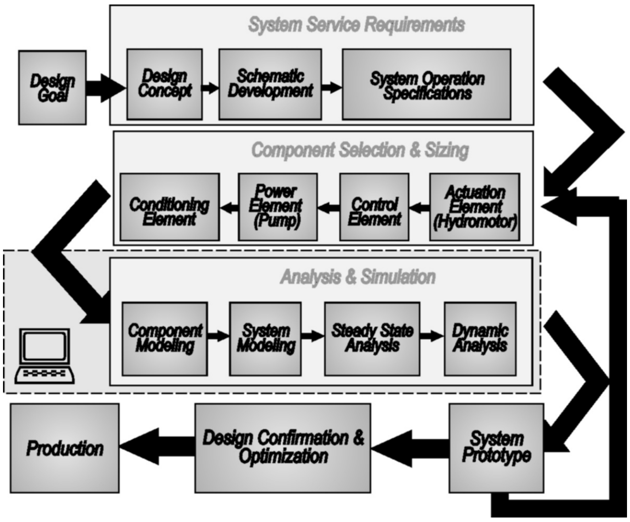

Fig. 6. HST system design procedure

Engineering world has long known that the analysis and simulation phase of fluid power system development is very important in producing a successful HST with minimum time and cost. To tackle this, at present time, highly demanding phase, an engineer must have powerful tools. It is totally unacceptable from a cost standpoint to permit the design factors of HST to be estimated and then fabricate the system to see if it works. The best tool available (one which is becoming more useful every day) is personal computer. Digital computer analysis and simulation of HST is now widely used and accepted as a desirable, and sometime essential, element of the design stage of major HST project. Design engineer, with access to a personal computer, may adopt one of three possible strategies, when considering its application to numerical analysis and simulation [20].

The first procedure treats mathematical equations that describe the behaviour of whole HST as any other system of differential equations (for dynamic analysis) i.e. algebraic equations (for stationary analysis). This system of equations is being numerically solved using any of the established numerical methods by writing the software code in one of the already mentioned programming languages. Although there are relatively lots of public or commercial libraries with FORTRAN/C codes for solving differential/algebraic equations, an engineer must be mathematical "genius" and computer expert in order to accomplish this task, due to high inherent nonlinearities in fluid power hydraulics. One more fact that goes against this procedure is that written computer program may be of limited use with respect to simulation of other HST. It also demands more time, but less financial resources to solve the problem compared to other procedures.

The second approach considers the use of any of standard simulation packages, easily adaptable to hydraulic fluid power application. At the Fluid Power Net web site [21], one can find more then twenty general-purpose packages for modelling behaviour of fluid power components and systems. The most prevalent are: MATLAB with SIMULINK, ASCL, VisSim, 20-Sim, BuildSim, MATRIXx, MathModelica, etc. These packages are very flexible, relatively simple and they do not demand big time consumption for model development. Many of these packages have optional (commercial and non-commercial) fluid power oriented toolboxes, like Hydraulic Block Set Toolbox for MATLAB [22] and HyLib for Modelica [23]. In addition, these packages have the ability to simulate operation of artificial intelligence (AI) controls like fuzzy logic, neural nets, etc., and can be used in hardware-in-loop applications. A very important feature of some of these packages (like VisSim) is that we can develop a control system by simulation, and after translating the code into C++ language embed it on a chip [5].

The third procedure involves the use of general hydraulic simulation packages. More then thirty general hydraulic simulation packages can be found at the market such as: BathFP, DSHPlus, AMESim, HyPneu, Flowmaster, Hopsan, HydroAnalyst, ITI Sym, etc [21]. The foundation of the analysis approach used in the most of these packages is visual modelling that relies upon the fact that all components consist of several basic elements (e.g., mass, damper, spring, friction, orifices, etc.). These software packages include a large number of the, so-called, generic components, stored in component libraries for the use in any number of HSTs. The component library in program contains all of basic design elements in the form of icons, models and data sheets. Special components, which are manufactured for unique applications, can be modelled and put into the component library, but there is no such flexibility as in general-purpose packages. The user simply joins the correct icons together, so as to form a complete system. A HST is composed of interacting elements and components. Therefore, once the element and component models are developed, the system model becomes a mathematical description of the way these elements and components interact. These software packages do not require high mathematical and computer knowledge from design engineers to be applied in HST system design. They are also relatively expensive and require many years and effort in their development.

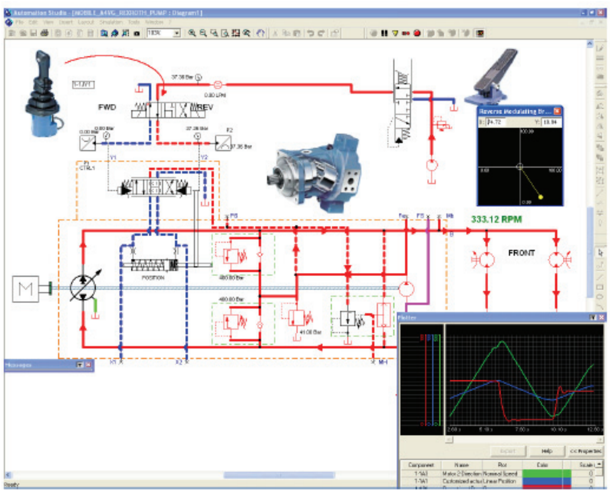

Fig. 7. An example of HST system modelling in Automation Studio [24]

Some of the software applications like Automation Studio give more opportunities beside system modelling and design. This software is innovative solution for design, simulation and documentation of fluid power and automated systems and therefore HST systems [24]. It has a module that enables users to extract project data, in order to create complete project documentation and save a significant amount of time. Automation Studio can also integrate the whole product life cycle, from deign to training and maintenance.

4. COMPUTERS IN MARKETING AND E-COMMERCE

The basic aim of every manufacturer is to give the proper and useful information to the potential customer about his products, in order to incite him to buy his goods. The Internet, that evolved into global business application, is ideal medium for such an action. It provides a direct link from the end user to the manufacturer, with access to important product information 24 hours a day, 365 days a year, worldwide.
Almost every significant world manufacturer of HST components and systems has its own web site with contact addresses, downloadable digitalized versions of the product catalogues and even various software packages that provide sizing calculations of a required product. However, static web sites that act as billboards of information are not the only way of presentation. Development of dynamic web cites and web oriented programming tools (DHTML, JAVA, PhP, ASP, SQL, VBNet, etc.), has brought about revolutionary concept for conducting global business, popularly known as e-commerce. Interactive web sites that configure products and produce the product geometry parametrically, create product drawings and printouts, and enable downloading the files for insertion into CAD design systems. Electronic RFQ (request for quote) automatically sends the product model number, configuration information and product drawings directly to the manufacturer and duplicates all information to the appropriate distributor. This opens the door for increased sales by providing design engineers important time saving information, product configuration for their application, drawing files and a products availability, which reduce cost and shipping time [25].

5. CONCLUSION

In order to prevail over existing concurrency from other technologies for power transfer, HST technology must make full use of its specific advantages and to utilize other technologies that can improve its characteristics. One of this is computer technology. This paper gives the insight in a few different aspects of present computer applications in HST technology: for control, data acquisition and condition monitoring, design & modelling, marketing & e-commerce). Enhancement of computer literacy in the world of fluid power engineers, associated with further improvement in computer technology, will improve current applications and promote new ones. With different computer applications, the stable market position of HST technology can be sustained long in the future.

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