MODELLING AND SIMULATION UTILIZED IN RESEARCH AND DEVELOPMENT OF MOBILE HYDRAULICS

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Mobile hydraulics include fluid power components and systems utilized in mobile machinery such as forest machines, excavators and hydraulic lifts. It has special features compared to the stationary i.e. industrial hydraulics. This paper gives an overview of mobile hydraulics and presents the benefits that can be achieved by employing modelling and simulation in order to carry out R&D of such machines.

Keywords: mobile hydraulics, modelling, simulation, R&D

1 INTRODUCTION

Computer simulation has been a powerful and generally accepted practice to carry out academic research in the area of fluid power. Universities have been making their own simulation packages and many thesis made during the last ten years deal with modelling and simulation. Due to lack of suitable software and sufficient computer power relatively small subsystems are being under investigation so far. Now the trend is into simulation models covering the complete machine systems. The rapidly increased computational power has created conditions for extensive numerical calculation. Figure 1 illustrates the development of CPU power (of PC's) during the last 20 years.

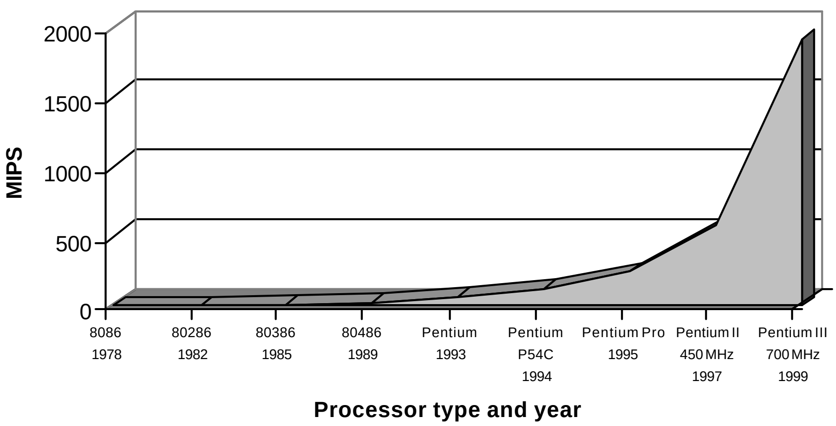

Figure 1. Development of CPU power

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The fluid power industry has also recently shown increasing interest towards simulation. Co-operative projects with industrial partners and academic institutes make possible to put the research results into practice in an optimal way. Simulation model itself is useless unless extra value for the product is gained based on the study done by means of the model.

One of the main benefits in co-operative projects is the two-way knowledge transmission between participants. The theoretical knowledge and understanding of the product performance is improved among the company people while the applications become familiar among researchers at university.

2 OVERVIEW OF MOBILE HYDRAULICS

The fluid power industry is traditionally separated between mobile hydraulics and stationary hydraulics. Because stationary hydraulics is mainly utilized in industrial applications it is also called industrial hydraulics.

The processes in the area of industrial hydraulics are typically periodic and seldom modified. The component systems are discrete since the valves usually perform one valve function only. The valves can be either types of on/off , proportional or servo valves. The primary power supplies used are in general electric motors and the number of pumps in system is not restricted. In practise the pump supply is also always sufficient considering both flow and pressure requirements of the system. The volume or weight limitations hardly ever cause difficulties.

Mobile applications are more complex. The space and weight restrictions in machines have a big influence on the fluid power system design hence big power/weight ratio is required. The working process itself and process environment constantly changes. The operations are performed outdoors under changing environmental conditions such as ambient temperature and moisture. This sets huge demands for adaptiveness and reliability of fluid power system.

The primary power source is typically one diesel engine per machine. Pumps are placed to the engine shaft and thus the number of pumps in the system is limited. The pump system must also be able to handle the limited power and therefore prevent the excess of diesel power available.

On the component level the main difference compared to industrial hydraulics is the mobile valve. Several directional valves (1-9) are placed into one common valve block (fig. 2). The compact design is achieved and the need of hosing is decreased.

Figure 2. Mobile valve

The mobile valve is normally of proportional type. Servo technology is found too unreliable and vulnerable for mobile conditions. Main spools are either electrically (proportional solenoid) or hydraulically pilot operated. They can be open centre type or closed centre with load sensing ability hence the valve can be used with LS-pumps.

There are also several valve functions integrated into the single valve blocks. The most common are pressure compensation, load drop check, pump flow sharing (anti-saturation), pressure relief and anti-cavitation (fig. 3).

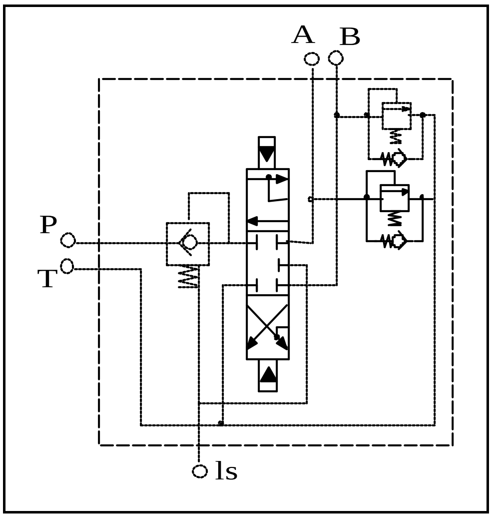

Figure 3. Schematic picture of valve section equipped with main spool, pressure compensator, load drop check valve, pressure relief valves, anti-cavitation valves and LS signal output

Mechanically mobile machines typically have 3-9 degrees of freedom when mechanism parts are considered as rigid bodies (fig. 4).

The purpose of use of such machines differs but the basic construction is more or less similar. The machines normally include transmission system, crane and an attachment with work hydraulics. Typical examples of mobile hydraulics are forest machines, excavators, personal lifts, drilling machines and agricultural machinery. Somehow typical work cycle for each machine can be determined although the process material and working environment might change considerably.


Figure 4. Examples of mobile machinery

3 MODELLING AND SIMULATION IN MOBILE HYDRAULICS

3.1 Motivation for simulation approach

The nature of mobile hydraulics makes the simulation approach exceptionally well justified.

Considering heavy machinery production series are relatively small and unit prices are high. Due to this physical prototypes are rarely available for machine designers and researchers.

There are also a lot of variables to be measured from the prototype machine. Comprehensive study of fluid power system of a mobile machine may require 50 flow and pressure measurements. Therefore the measurement equipment with the same amount of sensors must be installed. Sensors and wiring connections also tend to be sensitive to environmental circumstances such as moisture and dirt. These reasons make field measurements difficult to arrange and very costly. It typically takes weeks to arrange conditions for field measurements to test new ideas.

It gets even more time consuming if several machine configuration, mechanic or hydraulic, are desired to be tested. Changes in mechanical structure require a lot of manufacturing and installation work and a very limited number of variations can be tested in practice. The amount of possible hydraulic configurations depends on the number of hydraulic actuators and pumps in the system. For a mobile machine typically tens or even hundreds of possible combinations can be found.

Analysis of measurement results is difficult since equal conditions for separate measurements is in practice impossible to arrange. The results are affected by the variations in work process and performance of the machine operator as well varying environmental circumstances. A simulation model offers equivalent and repetitive conditions for qualitative analysis and thus comparison between different systems.

The basic construction of the mobile machines can be assumed to be quite constant over a long period of time. In this case carefully done and verified simulation model can be used as a design tool for years. All design modifications and R&D ideas can be examined by the model.

Based on these facts simulation study can be very beneficial by both technical and financial means in the area of mobile hydraulics.

3.2 Technical requirements for simulation approach

A simulation model of mobile machine is a complex entity including mechanism, fluid power system and control system.

- Due to the nature of mobile hydraulics, a special model library for mobile hydraulics components is unavoidable.
- At least the following submodels should be available
- variable displacement pump with controller (load sensing pump / constant pressure pump) and power limiter
- mobile valve including integrated valve functions
- oil cooler

models for load conditions and working process

Combined with mechanism models a complete machine model can be constructed. Since the complete model is relatively large, numerically efficient component models hugely increase the usability of the model.

The parameter values are important considering the accuracy and reliability of the model. They can be determined by means of component measurements or using the values available in manufacturers catalogues. The load conditions must be either measured or otherwise determined based on general engineering knowledge.

Commercial software is almost exceptionally implemented in a certain way which limits their suitability. They either lack of readily available component models or the software itself is not flexible enough for required modifications. In house software equipped with comprehensive component library form an effective engineering tool.

4 SIMULATION AND R&D

Research and development is a continuous project in industrial companies. Functionality, efficiency and dynamic behaviour of the machines need to be improved in order to maintain the competition ability and to answer to the customers' needs.

4.1 Energy efficiency

Energy efficiency is one of the main topics while considering the product development of mobile hydraulics. This can be motivated by several reasons. Naturally, since the primary power source of the machine is usually diesel engine, fuel economy is one of them. Even more important thing is the system temperature balance. The power losses in the system are converted into heat. The oil tanks of the machines are relatively small and the system temperature rises fast while hydraulic power is produced inefficient way. This has many unwanted effects. The oil cooler must be dimensioned larger which increases price of the machine and may cause volume problems in machine layout. In the worst case the primary motor must also be larger than needed in well designed and energy efficient system. This creates a chain reaction where heavier structures must also be used which increases the weight of the machine and so on.

The pressure and flow requirements vary remarkable during mobile machine operation. This sets demands for the system design in order to minimize the losses and thus maximize the efficiency. The traditional practice in mobile hydraulics is to use fixed displacement pumps with open-centre valves. Constant pressure systems are also used. However, the current trend is towards load sensing (LS) systems with variable displacement pumps. The basic reason for this is the supposition for improved energy efficiency. Nevertheless, this is not unambiguous in case of mobile machines.

In load sensing systems the supply pressure is determined based on the highest load pressure in the system. The best system efficiency is achieved when only one function is carried out at one time or when two or more simultaneous functions have the same pressure requirements. However, typically the pressure levels of simultaneous functions vary. In order to prevent load dependence and load interactions between simultaneous functions pressure compensation is utilized. Pressure compensator maintain nearly constant pressure loss across the main spool so the speed of an actuator remain constant and is a function of main spool opening only. This makes the machine control easier for operator and productivity is increased. Nevertheless, it usually means remarkable pressure losses occurring in pressure compensators.

In the following different systems are compared with respect to energy efficiency. In fig. 5 the typical situation is presented while three simultaneous functions are carried out.

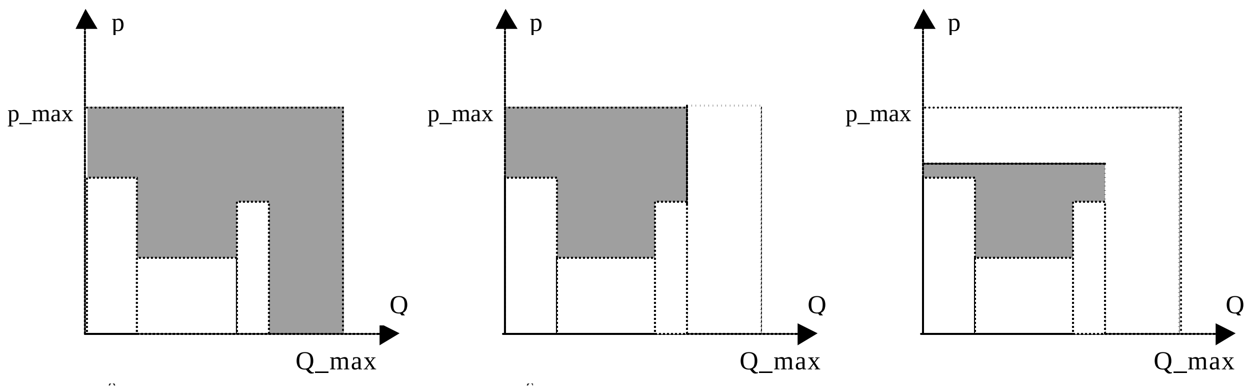

Figure 5. Energy efficiency of open centre, constant pressure and load sensing systems

Figure 6 presents the worst situation with respect to energy efficiency. It can be seen that load sensing system itself does not necessarily offer remarkable improvement in energy efficiency.

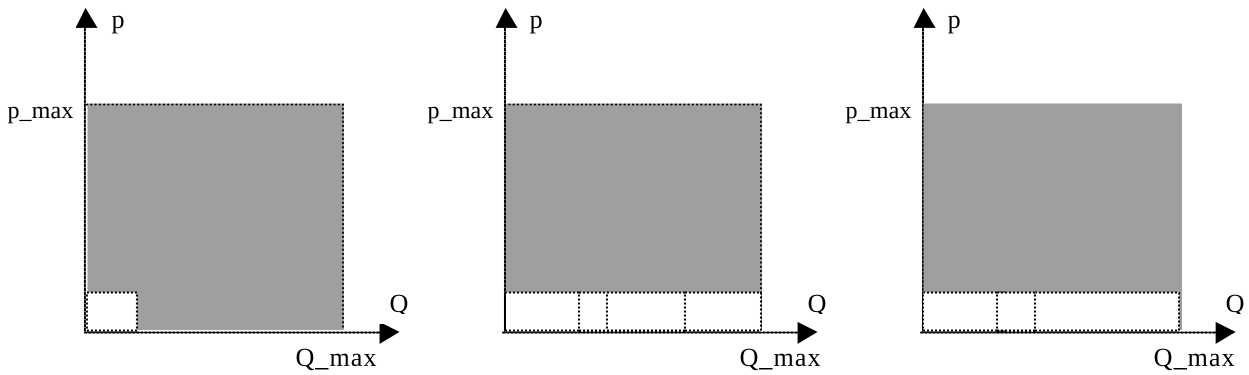

Figure 6. Energy efficiency of open centre, constant pressure and load sensing systems

4.2 Qualitative study of energy efficiency

For the machine designer the main question is how many pumps the machine should have and what functions should be grouped together. Considering pressure compensated load sensing systems the most advantageous design is achieved when the actuators with the approximately equal average pressure level are placed in the same pump system. As discussed earlier there can be hundreds of possible combinations.

The research procedure can be carried out in the following way

- Simulation model of the mobile machine is created
- Mobile machines typically undergo certain work cycles. The average test cycle is determined which is utilized to compare the alternatives.
- The loss work done per work cycle for each alternative system is examined by means of the simulation model.

- The heat generation of the system as a function of time can be solved when the loss work and active (oil cooling) and passive (heat transfer) cooling power is taken into account. The temperature rise in the system during consecutive work cycles is calculated. This can be done using some mathematics software available such as Matlab.
- The physical prototype tests are carried out with the most promising alternatives.

Different systems can now be rated by means of qualitative analysis. The accuracy of the results depends on how exactly the 'average' work cycle can be determined. Several work cycles should be investigated in order get reliable results for decision making.

4.3 Simulation example

In the following an example considering energy efficiency study is presented. The simulation model utilized covers a forest machine having 7 degrees of freedom, 9 hydraulic actuators and variable number of LS-pumps.

The simulation model is employed to compare systems having different number of pumps. The study is accomplished by methods discussed in 4.2. As seen in fig. 7 the change from 1 pump system to 2 pump system is advantageous and considerable difference between temperature balances can be seen. However, the improvement from 2 pump system to 3 pump system is only marginal and considering financial aspects hardly worthwhile.

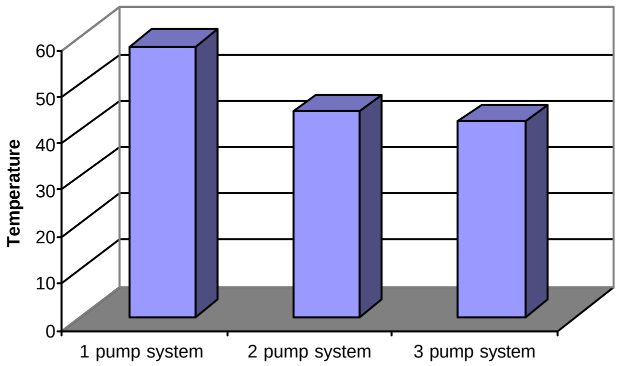

Figure 7. Temperature balances of three different systems

5 SUMMARY

The basic features of mobile hydraulics were presented. The usability of modelling and simulation approach in this particular area was discussed and motivated. As an example of R&D targets energy efficiency study was briefly described.

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