Numerical Simulation of the Fluid Control Systems by AMESim

Michel Lebrun

University Claude Bernard, Lyon

Daniela Vasiliu, Nicolae Vasiliu

University Politehnica of Bucharest

Abstract: Many different modeling and simulation software packages were created to perform studies in the fields of automobile, aerospace, robotics, offshore and general hydraulics engineering but none offered the full range of capabilities needed. There were deficiencies in the numerical capabilities, in the graphical interface and in the general modeling concept. The AMESim package was developed to overcome these limitations. This paper gives a description of the technical features, which were central objectives in the design of the software, and some examples of typical applications. A large amount of experience has been accumulated through more than 400 consultancy projects between the IMAGINE company, which created the software, and strong industrial companies.

Keywords: Modelling and Simulation Software, Fluid Control Systems, Electro Hydraulic Servo Systems

Michel Lebrun graduated Applyied Mechanics in INSA Lyon in 1970 and became Ph.D. in 1978 in the same institute, obtaining the diploma of “The Best State PhD Thesis”. In 1986 he obtained the title of State Doctor and founded SOCIETE IMAGINE, a research company devoted to the fluid control systems. The company developed the most powerful software for modeling and simulation the dynamics of the engineering systems – AMESim – used by all the innovative companies all over the world. In 1990 Michel Lebrun awarded the GOLD MEDAL of the FRENCH DEVELOPMENT INDUSTRIAL SOCIETY. The main fields of activities were: the development of the Bond Graph theory as a tool for physical modeling of the technical systems; modeling and simulation of the automotive components and systems.

Vasiliu Daniela graduated in Mechanichal Engineering from “Politechnica” University of Bucharest in 1981. He became a Ph.D. in Fluid Control Systems in 1997 at the same university, after a research stage at INSA Toulouse. From 2001 she is state professor in the “Politechnica” University of Bucharest, as head of the CAD/CAE Laboratory from Power Engineering Faculty. She worked also for the industry, as project engineer in the National Turbomachinery Institute from Bucharest. In 1994 he joint INSA Toulouse as associated research professor, and SOCIETE IMAGINE from France, as associated researcher. She is also working as a scientific advisor for IT in the Romanian Environmental Engineering Institute. She is working mainly in modelling, simulation and dynamic identification of the electrohydraulic control systems.

Nicolae Vasiliu graduated in Hydropower Engineering from Politechnica University of Bucharest in 1969 as a lider of the promotion. He became a Ph.D. in Fluid Mechanics at the same university, after a research stage in Von KARMAN Institute and Gand State University. He is state professor in the Polytechnical University of Bucharest from 1994, as the head of the Fluid Control Laboratory from Power Department. He worked always for the industry, as project manager or scientific advisor. In 1980 he joint the Hydraulic Control Team from the Romanian Aerospace Institute. In 1994 he joint INSA Toulouse as associated professor, and SOCIETE IMAGINE from France, as scientific researcher. He is the general director of the Romanian Innovation Agency, and he is representing Romania in FPNI. He is working mainly in modelling, simulation and dynamic identification of the electrohydraulic control systems.

1. Need of the Multiport Approach in System Modeling and Simulation

In the signal port approach, a single value or an array of values are transferred from one component block to another in a single direction. This is fine when the physical engineering system behaves in the same way such as with a control system. However, problems arise when power is transmitted. This is because modeling of components that transmit power leads to a requirement to exchange information between components in both directions. In order to use a signal port approach in this situation, two connections must be made between the components where physically there is only one. This leads to a great complexity of connections and means that even very simple models involving power transmission appear complex and unnatural.

In contrast to the signal port approach, with the multiport approach, a connection between two components allows information to flow in both directions. This makes the system diagram much closer to the physical system. Normally there are two values involved and the theory of bond graphs provides a good theoretical background into the relationship between these values and the power transmitted. However, there is no limitation in the number of quantities involved. There may be one quantity or three or more quantities. When there is only one quantity, the situation is just like with signal ports. Thus, signal ports can be regarded as a special case of multiports.

AMESim has always used the multiport approach and Figure 1 shows part of a simple electro hydraulic system using multiport block diagrams. Figure 2 shows the same system with signal ports. The control for the valve is identical in both cases since for this port, the multiport reduces to a signal port. However, for the hydraulic and mechanical ports, the extra connections needed for the signal port approach are apparent.

2. Numerical Capability

The analysis of the steady state and dynamic behavior of an engineering system leads to a mathematical model of the system. This is in the form of algebraic, ordinary differential and partial differential equations. More recently, differentialalgebraic equations are also used to model the system.

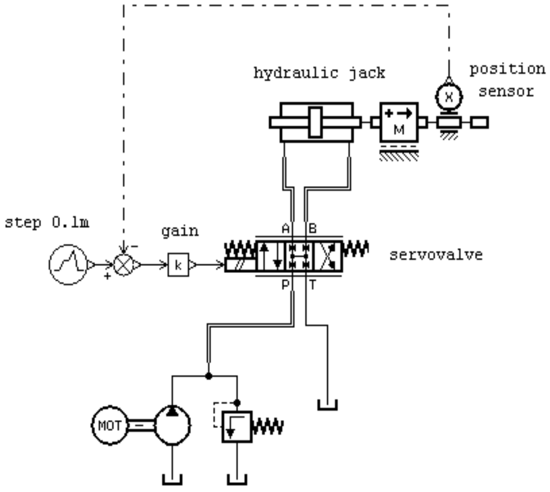

Figure 1. The multiport approach

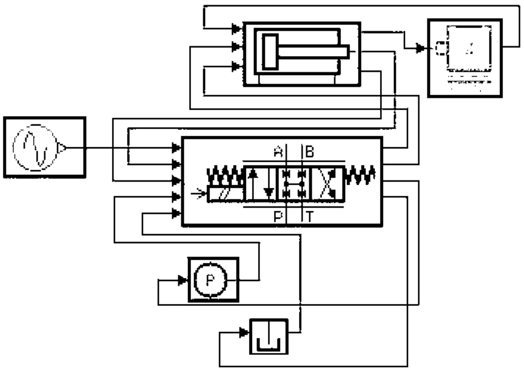

Figure 2. The signal port approach

The role of simulation software is to provide an environment in which this model can be solved efficiently. For models with large numbers of partial differential equations, there are specialist packages such as those for computation fluid dynamics. Such software is used for detailed analysis of individual components of a system. However, it is often necessary to simulate a completely engineering system or a subsystem of it. The concept of the virtual prototype, in which physical prototypes are replaced by mathematical computer models, makes simulation of this type vital. In this case, it is normal to reduce any partial differential equations to ordinary differential equations. This leads to models with either ordinary differential equations (odes) or differential algebraic equations (daes). Many general and specialized simulation software packages are available for solving such systems of equations.

Models arising from engineering systems vary greatly in their character. Thus the equations of the model can be: linear, non-linear, numerically stiff i.e. with very small time constants compared with the overall simulation period, oscillatory, continuous, discontinuous. A large variety of numerical integration methods can be employed to solve such problems. Traditionally the user of simulation software is presented with a menu of typically seven methods from which a choice must be made. Selection of the wrong method may lead to failure or unnecessarily long run times. Even specialist numerical mathematicians find such a choice very difficult. The situation is made worse because the characteristics of the equations may change during the simulation. Thus, initially they may be numerically stiff but become very highly oscillatory when a valve opens during the course of the simulation. It is unreasonable to expect the user to stop the simulation at the point where the characteristics change and then restart with a different integrator.

AMESim attempts to automate the process of switching between methods. First, the presence of daes is detected and an appropriate is employed. This is a much-modified version of the famous DASSL algorithm. If the equations are purely odes, a modified version of the LSODA integration algorithm is employed. This algorithm uses 17 different methods and monitors the characteristics of the equations detecting stiffness and the absence of stiffness. Switching is organized between two distinct solvers. An ADAMS code with 12 different methods is used when the equations are non-stiff. A GEAR code with five different methods is used when the equations are stiff.

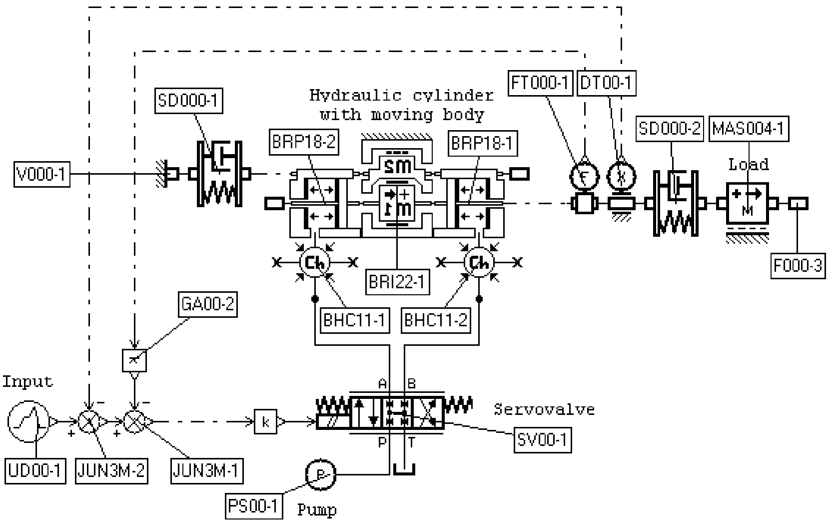

Figure 3. System built using mostly standard symbols

Both DASSL and LSODA use linear multistep methods. These methods are noted for intolerance of discontinuities. For this reason special discontinuity handling procedures are incorporated in AMESim. When we use a calculator to compute the sine of an angle, we happily accept the result displayed. A few decades ago, the process was more difficult and there were a number of methods available for performing the calculations. We would have had to select a method from those available. Perhaps we would have tried several methods to confirm the result was accurate.

This same process of automatic selection of method and of increasing reliability is already beginning to happen with integration algorithms for odes. Much progress has been made. Perhaps in 10 years we will be as confident in ode integrators as we are now with our calculators. Integrators for daes are less highly developed but are improved rapidly. The policy with AMESim will be to regularly update the numerical solvers to take advantage of new developments.

3. Full Graphical User Interface

Many older simulation packages were developed before modern graphical user interfaces were available. The only graphical facilities provided were for producing simple plots of results. The suppliers of these packages have had to introduce new graphical preprocessing facilities to build the system. More modern software has been designed from the start with a full graphical user interface. Whenever possible, icons for components were based on internationally recognized standard symbols. Thus for hydraulic systems icons are based on CETOPS symbols. Figure 3 shows a typical example. Where there are no such standardized symbols, icons are constructed which can be instantly recognized by engineers working in the field. Figure 4 shows a display of a fuel injection system employing icons of this type.

Throughout the simulation, process the system diagram is displayed. Thus for example when parameters are changed for a particular component, the user points at the icon in question and clicks the mouse button. This produces a menu of items that may be changed. Similarly to plot graphs of results, the user points at the component and clicks the mouse button to produce a menu of items associated with the component that may be plotted.

Normally at some stage in the simulation process, a demonstration must be organized. If a good system diagram is displayed, and parameters can be changed and results plotted rapidly, a good impression is created. If ‘what would happen if?’ questions can be answered quickly, the demonstration is very successful. If the system diagram looks unnatural or if it is removed from the process of changing parameters and plotting graphs, a demonstration is much less successful.

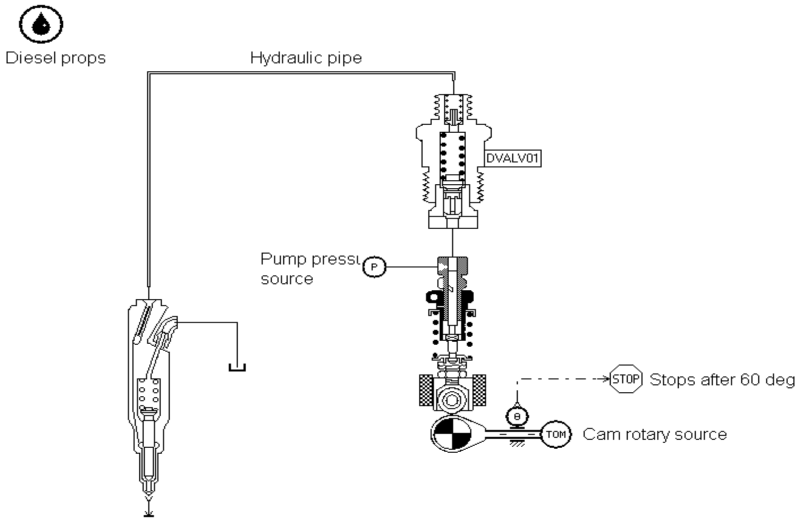

Figure 4. System using mostly ‘natural’ symbols

4. Advanced Modeling Environment

AMESim was designed for use in a whole range of industries. Each industry has a variety of systems for which simulation is to be employed. The physical system is made up of components, which are assembled to form the complete system. AMESim follows precisely the same strategy. Each physical component is represented by an appropriate icon and is associated with one or more submodel. The icons and associated submodels are assembled to form the model of the complete system. In addition, just as it is impossible to connect for instance a mechanical spring to the inlet port of a hydraulic pump, AMESim makes checks to prevent such connections. To make this process work, it is necessary to customize a collection of icons and submodels for a particular industry. This can be done at the IMAGINE company but since all the tools are available to perform this task, a competent AMESim user can perform this task.

5. Expanding AMESim

Associated with AMESim is another utility, which partially automates the process of building new submodels. This is called AMESet which is the Submodel editing tool. It is a utility, which allows the specification of a new submodel to be entered, and skeleton code to be produced. The submodel writer then takes the submodel code and enters the equations of the submodel. It would be wonderful if it could be said that the process of writing submodels was very easy. However, in truth writing good submodels does require great care, attention to detail, an understanding of the physics involved and some flair and talent. However, once the submodel is written and tested, it can be reused over and over again in completely different systems. On many occasions, just two or three new icons and submodels added to the AMESim standard library are all that is needed to adapt AMESim to your requirements.

6. Interfaces with other Software

The concept of the virtual prototype has already been mentioned. This concept implies simulation of large systems which will contain subsystems from particular domains. Thus, a complete model of a car might contain mechanical (multibody), hydraulic, pneumatic, electrical and thermal subsystems. Traditionally software has been developed for particular domains. Much very valuable simulation can be performed with this domain specific software. However, it is possible that there are complex interactions between subsystems from different domains. These interactions cannot always be ignored. This leads to the concept of multidomain or mechatronics simulation. How then is this to be achieved? One approach is to take a domain specific software and add a capability in other domains. This is done in many software packages including AMESim. The approach can be very successful if the ‘foreign’ subsytem is reasonably simple. The limitations of this strategy are that a software producer will have strong expertise in a particular domain and very limited expertise outside of this area. To produce a good collection of submodels in a new domain requires an enormous investment in time and money. It would also produce great duplication of effort. There is another more fundamental objection. Software from each domain has a specialized user interface, which has developed over the past decade. This user interface is not the result of chance but rather the result of genuine needs. To illustrate this point compare the typical multibody software user interface with the typical hydraulic software interface. The multibody software has the following characteristics: it is very geometrical with lengths and angles represented to scale; it is 3-dimensional and often axes are displayed; it is useful to be able to rotate the axes and display the system from a number of view points. In contrast for the hydraulic software interface: the display is a schematic and lengths and angles are not represented to scale; the physical system will be 3-dimensional but the schematic is mapped onto 2-dimensions; it is not meaningful to display axes; it is not useful to rotate the schematic and display from a number of view points. Animation is unimportant and not normally provided; the main way of displaying results is simple graphs, bode plots. In view of these differences, AMESim is interfaced with other software to allow more complex mixed domain simulation. Each subsystem is built with the appropriate domain specific software. A combined simulation is performed and results from each domain examined using the post processing facilities of each software.

An interface is available with the multibody software ADAMS (Figures 5 and 6). This is particularly useful in automotive applications. Also available is an interface between AMESim and MATLAB/Simulink. This allows the controller design facilities of MATLAB/Simulink to be used for a hydraulic system. The non-linear hydraulic system can be linearized about an operating point or the full hydraulic system converted to an S-function for use within Simulink.

A strong Hydraulic Component design library is available in AMESim (Figure 7). This allows a realistic analysis of the physical phenomena. Figures 8 and 9 show the results of such an analysis for the power steering from Figure 6. Figure 10 and 11 show the flow and pressure evolution for a common rail radial piston pump (Figure 12). Interfaces between domain specific software packages are now a reality. Already interest is developing in extending the process to three or more packages with AMESim providing the hydraulic capability. This is likely to happen in the near future and the virtual prototype will truly have arrived.

It is no longer necessary to appeal for greater use of simulation in the engineering industries. There has been a steady spread of its use from large sized industries, to medium sized industries and now to small industries. Within each industry there has been an expansion of simulation from the research department to the drawing office.

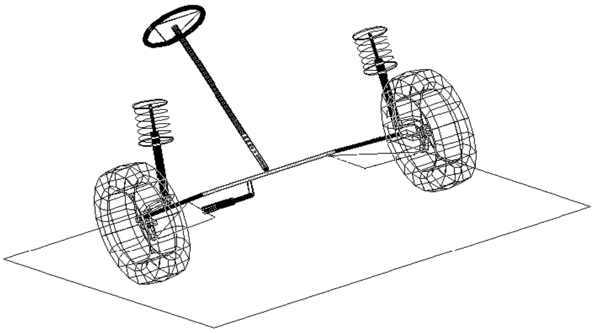

Figure 5. The multibody part of a power assisted steering system modeled using ADAMS

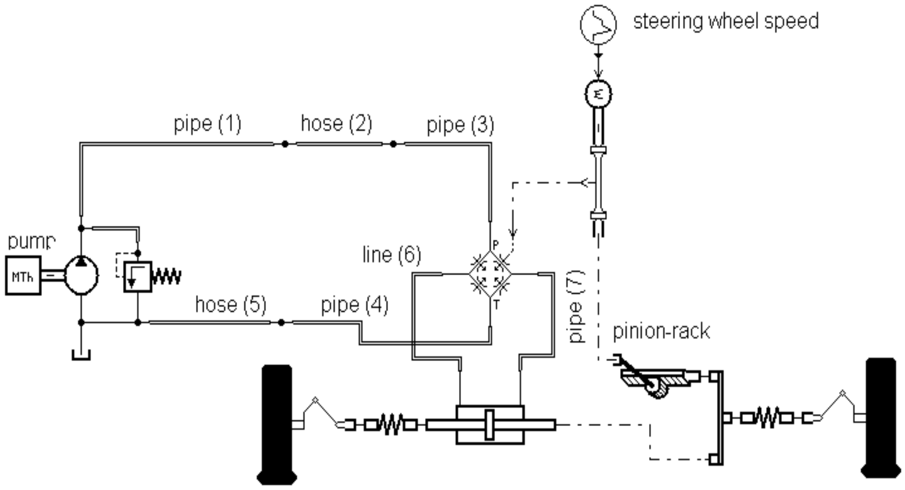

Figure 6. The hydraulic part of a power assisted steering system modeled using AMESim

This movement could not have taken place without a record of success for simulation in the design process. The key factors have been: reduction of the need for testing physical prototypes; more thorough testing of the product; convincing the potential client that the product will be worthy; cutting the time to bring the product to the market place; a better understanding of the product. In the automobile industry, the process is well advanced. It is becoming increasingly common for companies to require their subsystem suppliers to provide a model of the subsystem before the physical subsystem is delivered. However, despite this success there are plenty of instances of poor models of engineering systems. Below are some classic blunders. The list is far from complete but is representative of the problems that occur: failure to observe a fundamental physical phenomenon such as conservation of mass; failure to check model inputs to eliminate gross errors such as a stiction level less than a Coulomb friction level; failure to perform adequate testing of modules within the model; inappropriate level of complexity e.g. too much detail and high dynamics within a large system; use of a physical formula outside its domain of validity (often leading to numerical problems); domain violation in using of mathematical functions e.g. square root of a negative number (this often occurs when the integrator is iterating to convergence with an implicit method); mismatch of physical units; calling function or subroutines with incorrect arguments; problems in modeling physical phenomena using discontinuities. These problems can lead to bad results but also to excessive times to construct, debug and validate a model.

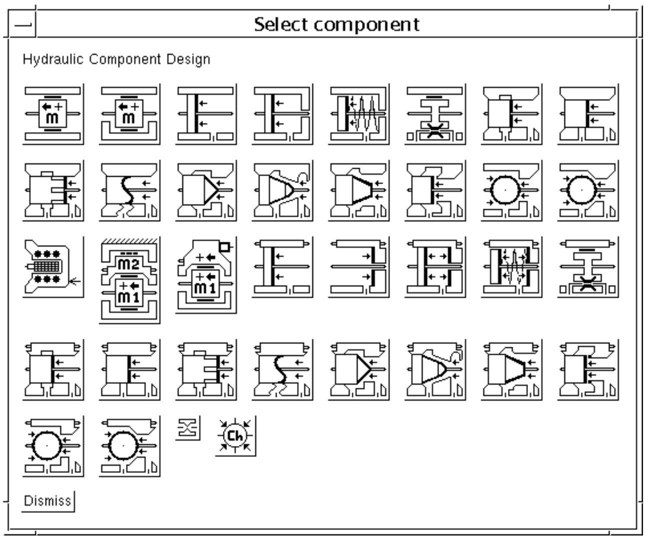

Figure 7. The AMESim Hydraulic Component Library

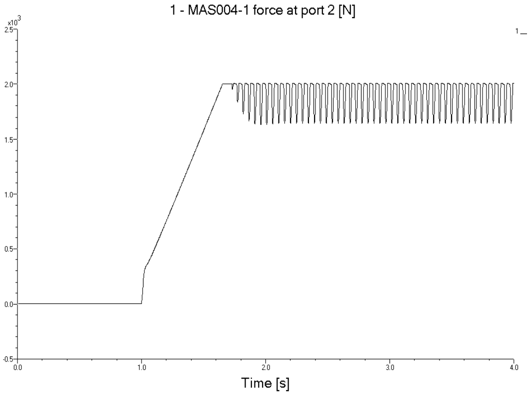

Figure 8. Input signal of the power steering (constant angular velocity of the steering wheel)

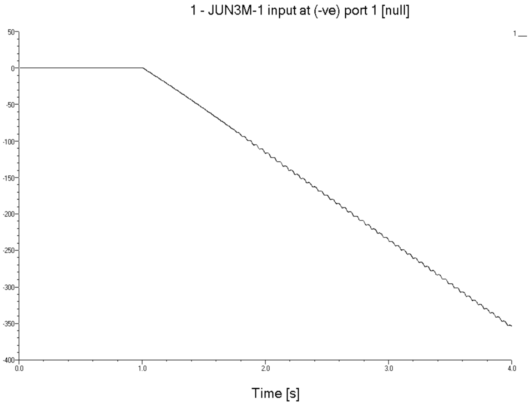

Figure 9. Output signal of the power steering (force applied to the steering arm)

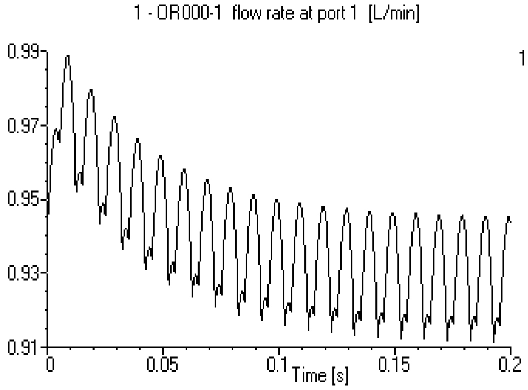

Figure 10. Flow variation in the delivery port of a common rail radial piston pump

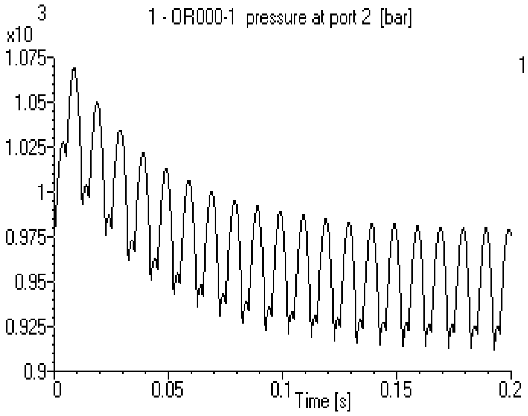

Figure 11. Pressure variation in the delivery port of a common rail radial piston pump

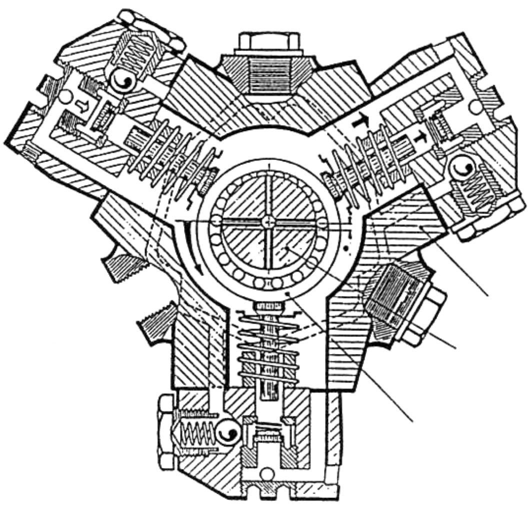

Figure 12. Common rail high pressure pump

7. Conclusions

The main aim of the AMESim is “To create Good Models without Writing a Single Line of Code” (Lebrun and Claude, 1997). An important prerequisite of the basic element library is the creation of extremely well tested, reliable and reusable submodels that a user can employ with complete confidence (IMAGINE, 2005). The writer of the basic element library must be competent in all the modeling skills. However, the user of the basic element library is relieved of the need to write code and formulate the mathematics. Understanding of the details of the physics is not needed but decision on assumption is necessary which imply some knowledge of physics. Understanding of the engineering system and an ability to interpret results is still important. Experience in training design office staff to use of the basic element library suggests that it is learnt very rapidly. The possibility of quick high level technical developments as ABS, EBS, common rail multipoint injection systems, electro hydraulic automatic transmissions, self tuning hydraulic and pneumatic suspensions, hydraulic power steering, fly-by-wire systems and many others (Mare and Cregut, 2001; Lebrun, 2004). Companies like AEROSPATIALE, MATRA, BOSCH, FERRARI, DAIMLER-CRIYSLER, GENERAL MOTORS, etc. are currently using this modeling and simulation software for future developments.

Academic training programs are now developed in different countries, including Romania, for teaching the software in the terminal years (Vasiliu and Vasiliu, 2005), and for applied researches (Vasiliu, et al., 2003).

REFERENCES

1. IMAGINE SA (2005), **Advanced Modeling and Simulation Environment**, Release 4.2.1. User Manual, Roanne.

2. LEBRUN, M., CLAUDE, R. (1997), **How to create Good Models without Writing a Single Line of Code**, Fifth Scandinavian International Conference on Fluid Power, Linköping.

3. LEBRUN, M. (2004), **EHA's Model Reduction Using Activity Indexes. Recent Advances in Aerospace Hydraulics,** INSA Toulouse.

4. MARE, J.C., CREGUT, S. (2001), **Electro Hydraulic Force Generator for the Certification of a Thrust Vector Actuator**, Recent Advances in Aerospace Hydraulics, INSA Toulouse.

5. VASILIU, N., CĂLINOIU, C., VASILIU, D., OFRIM, D., MANEA, F. (2003). **Theoretical and Experimental Researches On A New Type Of Digital Electro Hydraulic Speed Governor For Hydraulic Turbines**, 1st International Conference on Computational Methods in Fluid Power Technology, Melbourne.

6. VASILIU, N., VASILIU, D. (2004). **Electro Hydraulic Servomechanisms with Two Stages DDV for Heavy Load Simulators Controlled by ADWIN**, Recent Advances in Aerospace Hydraulics, INSA Toulouse.

7. VASILIU, N., VASILIU, D. (2005). **Fluid Power Systems**, Vol.I. Technical Publishing House, Bucharest.