University of Craiova
Faculty of Automatics, Computers and Electronics

Doctor's Degree

Unconventional Driving Systems for Driving Robots

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Summary

This doctor's degree, ***"Unconventional Driving Systems for Driving Robots"***, is the outcome of a constant activity of study and research.

The current research was meant to have both a theoretical and practical value, a fact which can be seen through the author's participation in national and international conferences with scientific works, having as support chapters of the thesis, and also through the designing of some experimental prototypes of action and control systems with rheological fluids based on the theoretical-scientific ground developed throughout this work.

The achievement of the research activity and of the aimed objectives involved both the knowledge and the thoroughgoing study of the concepts and analysis methods of *the specialized disciplines*: mechanics, the theory of systems e signals, mechatronics, special mathematics, sensors and instrumentation, data acquisition systems and process computers, of the *fields specific to* the *studied phenomena*: the theory of the fluid viscous running, the theory of the magnetic field distribution, the designing of the electromagnets based on ferrite, and also *the employment of the algorithms and soft programs* specific to the automatic adjustment theory, of the *CAD/CAM AutoCAD, Autodesk Inventor media*, and the integrated programming media AutoLISP and Visual BASIC, of the *development systems with microcontrollers and of the data acquisition systems* with the associated programming media.

The obtained results of the current work would not have been possible without a solid theoretical approach, meant to gain insight into the intimacy of the dynamic processes and without the doing of some refined experimental research, meant to allow the investigation of these phenomena with a high level of complexity and particularity specific to the approached theme.

Chapter 1: SMART MATERIALS

In this first chapter it was done a defining of smart materials from the point of vieue of their adaptability, multi functionality and information processing. A brief history of the development of the field was dealt with, being made a description of the main functions of this kind of materials, too.

The author did a brief description of the representative smart materials and their fields of applicability, offering an overview on "smart materials". There were also introduced the main development directions for each material, their advantages and disadvantages and also a classification of then on fields of applicability..

Chapter 2: ANALYTIC MODELS AND PROPERTIES OF SMART FLUIDS

The second chapter of this thesis does a description of the rheological fluids, displaying their structure, physicochemical properties, fields of applicability, and a number of representative applications existing on the market.

Then it was dealt with modeling of rheological fluids. It was also done a roundup of the fluids, and also the formal descriptions of their properties and behavior, presenting the two main behavioral patterns of the Newton and Hooke viscous flour.

There are also dealt with the main physical sizes which intervene in the description of the constituent models, namely viscosity, the viscoelasticity of fluids, and kinetic viscosity.

In order to describe the viscoelastic behavior of the rheological fluids the following

models have been introduced: Maxwell, generalized Maxwell, Kevin-Voight, extended Maxwell and Kevin-Voight, Burger.

More, in this chapter it is also introduced a graphic method for the fluid study.

There are also introduced the mathematics models used in describing viscosity: Newtonian, Bingham Oswald-Waele, Herschel-Bulkley, Carson, Carreau, Cross.

It was done a classification from the point of view of the viscosity of the Newtonian and non-Newtonian fluids, examining plastic, dilated and pseudo plastic fluids, dealing with the evolution of viscosity in time.

For one of the main producers of magneto-rheological fluids and their applications, namely Lord Company, there are introduced some applications of this company. The magneto-rheological fluid used in this work was manufactured by Lord Company.

It is introduced a simplified algorithm of choosing the rheological fluid and the field excitation generator depending on the type of the application.

At the end of the chapter it is done a comparative description of the two types of rheological fluids: electro-rheological and magneto-rheological.

Chapter 3: Fuzzy Controllers in Rheological Fluid Driving Systems

In the third chapter of the thesis it was done a study of applying the fuzzy algorithms in rheological fluid action systems. There were introduced the principles of fuzzy controllers, explaining the basic concepts and the internal structure of such a controller.

Thus, it was explained the database and the basis of rules of a CLF, and also the inference mechanism displaying MAX-DOT, MIN-MAX, Tsukamoto and Sugeno methods.

Moreover, it was dealt with aspects found in the development of the fuzzy control laws. It was done a comparison between fuzzy controllers and conventional controller's reviewing the PI, PD and PID controllers.

It was also done the approximation of a CLF with the help of a PI virtual controller based on the cvasiliniar fuzzy model.

Furthermore, it was done a study in which it was introduced the robust structure of self tuning for PI and PD fuzzy controllers. Thus there were introduced the member slip functions, the plate factors, the basis of rules and the self-tuning mechanism.

In the last section of chapter it was done a study of the fuzzy controller and sliding mode control.

Chapter 4: THE DESIGNING AND MODELLING OF A MAGNETO-RHEOLOGICAL VALVE-CONTROLLED SYSTEM

In this chapter it was done the modeling of a magneto-rheological valve system.

The study of the dynamics of stop-valve, having as fluidic agent the rheological liquids at different commands: step entrance of the pressure variation, step entrance of the flow variation, step signal of the energizing field, stressed the interval phenomena which were constitutive part of the research agreement.

It was done a case study of the structures of smart liquids for the stop-valve, mathematically determining the distribution of the flow speed, a 3D graphically represented

result in Matlab medium. Using these results it was studied the dynamics of a stop-valve at a step entrance of the energizing field and at a step entrance of the pressure variation. Using a pre-established set of value it was done the representation, through 3D visualization, of the results using Matlab medium.

At the end of chapter it was dealt with a servomotor structure based on the stop-valve architecture having as a result the mathematic model of the former.

Chapter 5: THE EXPERIMENTAL PLATFORM FOR ESTABLISHING THE CHARACTERISTICS OF MAGNETO-RHEOLOGICAL VALVES

It was done a stand for the experimental determination of the rheological stop-valves.

Conceptually, the platform consists of the drive block of the rheological fluid, the generation block of the excitation field and the proper electro valve.

The final result of these determinations is the dependence of the flow rate through the intensity valve of the magnetic field of excitation and applied pressure.

The platform is created in a modular way, so each ensemble con be replaced easily without mechanical or any other changes.

The platform is a complete stand test and consists of the following subsystems

- the pneumatic system
- the hydraulics system
- the electric and electronic system
- the sensory system
- the acquisition system of the rheological parameters
- the acquisition system of the magnetic field parameters
- the software programs related to the system acquisitions.

The acquisition of the parameters and the control system is done with the help of the Simulink software program through the Quanser acquisition board and a PC computer.

The acquisition of the intensity of the magnetic field is done with the help of a development system made with a PIC microcontroller, through a magnetic probe.

Although it is a prototype it is quite capable of establishing industrial determinations.

Although the platform has been done for testing and establishing the parameters of the magneto-rheological valves, it was thus conceived that, with minimal changes, it cam test electro-rheological valves, too.

For the final accomplishment of this test stand, there have been done more test variants, which were then perfected, from various points of view, that is, the constructive view, that of the used materials and of the minimizing the measurement errors.

As the parameter experimental determination needs the determination repetition for several times, the command model allows the automatic reiteration of the acquisition cycle in a finite loop.

The result of this repeated acquisition of a parameter being provided under the form of a vector, it was created a Matlab program which generates a matrix which has as constitutive vectors the values of each determination. The problems arisen from creating this program can be seen in the irregularity of the vector dimensions, in as for as the number of elements is concerned. The obtained matrix is used for the comparative visualizing of the acquisition cycles', being reseeded in the 3D Matlab representation of the results.

Chapter 6: THE EXPERIMENTAL RESULTS FOR DIFFERENT CONSTRUCTIVE TYPES OF MR VALVES FOR DIFFERENT TYPE OF ELECTROMAGNETIC FIELD

There were established the parameters for the rheological valves manufactured by the author. They differ through their constructive form the material of the valve body, the direction of fluid flow in magnetic field, the surface fluid found in a magnetic field and the magnetic permeability of the used materials.

Thus there were established the parameters for a cylindrical rheological valve, baving the form of the cylindrical crossing channel with diameters of 3,5 and 7 mm, with the direction of the fluid flow perpendicular on the lines of the magnetic field, made of steel. Although the used material should not diminish the magnetic field. The fact that the valve is cylindrical short circuits the field lines significantly diminishing its effect on the fluid. Due to this it is necessary the existence of powerful magnetic fields for this kind of valves. Another solution would be the direct touch between the fluid and the magnetic field generator ferrite, but this constructive solution requires the permanent attachment of then magnetic circuit to the valve.

The used material also requires the limiting of the generation frequency of the magnetic field to 200 Hz, a higher frequency leads to the material saturation.

For an adequate magnetic field the rheological effect was firmly established, for high values of the field intensity the movement being blocked.

Advantages: under the action of the magnetic field the solid particles “adhere” to the walls, the metallic material magnetizing in the magnetic field, easy to process; it is not affected by the oil existing in the magneto-rheological fluid; it is very pressure-resistant; a cheap material.

Disadvantages: if the cylinder table is big it diminishes the magnetic field intensity inside; a part of the magnetic field lines closes through the valve body, diminishing its effect; the material saturates at a frequency higher than 200 Hz of the generation power of the electromagnetic field.

There were established the parameters for the same type of constructive valve made of plastic, having the form of the crossing channel with diameters of 1.5, 2, 3 and 4 mm. The major difference is the fact that the constructive material of the valve is the plastic. It has been noticed, during testing, that this type of valve behaves better, being necessary magnetic fields of relatively love intensity for blocking the movement.

Advantages: easy to process; it is not affected the existing oil of the magneto-rheological fluid; pressure-resistant; chap material; it can work to high generation frequencies of the magnetic field.

There were established the parameters for the same constructive type of valve made of ferit. The major difference consists in the fact that the fluid flow direction is along the field lines for one and the same valve, a thing which diminishes significantly the rheological effect of viscosity growth.

Advantages: direct touch with the fluid of the magnetic field generator; it is not affected the oil existing in the magneto-rheological fluid; pressure-resistant; it can work at very high generation frequencies of the magnetic field.

Disadvantages: it can be done through special molding techniques; it can’t be processed then; the viscosity growth is maximum along the flow shaft, along the field lines, a thing which diminishes quite a lot the blocking effect of the movement; the magnetic field generator is integrated in the valve structure.

There have been established the parameters for a valve of the same constructive made of plastic, having the route of the cylindrical crossing channel maze-like shaped. The major difference consists in the maze-like shape of the crossing channel. It has been noticed during testing, that this type of valve behaves better, being necessary relatively low intensity magnetic fields for blocking the movement.

Advantages: easy to process; it is not affected by the oil existing in the magneto-rheological fluid; pressure-resistant; cheap material; it can work at high generation frequencies of the magnetic field; the maze-like channel rises the interaction surface with the field lines, the form of the channel is also characteristic to blocking a viscous flow.

Disadvantages: it is difficult to perform the direct contact of the fluid with the magnetic field generator without its integration with the valve structure.

In the case of a practical designing of a stop-valve the general parameters are of uttermost importance, imposing the conditions of establishing all the constructive parameters.

Chapter 7: THE DYNAMIC CONTROL OF AN MR VALVE PNEUMATIC PISTON

In the first part of this chapter it is introduced a dynamically controlled pneumatic piston, made by the author, through the help of a rheological stop-valve. The major advantage of such a practical solution consists in the absolute control of a pneumatic piston dynamics or a rheological one obtained by adding to its structure an integrated component, a hydraulic piston-rheological valve. This acting solution represents an innovation in acting pneumatic pistons; a solution which is not to be found in the literature of the genre.

This experimental platform was done as an open structure, being possible to be used as a didactic element, too. The platform was created and used for the study of this type of pistons, namely for establishing the parameters of the rheological valve, depending on the piston size and the work pressure.

The platform disposes of a complete system of establishing the piston behavior, for this purpose being used a part of the modules introduced in chapter 5, namely the acquisition system Quanser, the sensor system for determining the displacement, the system pressure sensor, and the magneto-rheological valve – magnetic field generator module. The command and data acquisition is done with the help of the Quanser acquisition board using the Matlab&Simulink work medium.

The next subchapter introduces the hyper redundant robots. It is presented the evolution, the existing constructive variants, the acting modes and their applicability fields.

The hyper redundant arm made of continuous flexible elements, elephant trump type, is especially dealt with. In fact, it is done a constructive variant with only one pressure chamber of this kind of arm. By controlling the pressure, it is, in fact controlled the grip function through the coiling of the arm. The made hyper redundant arm was connected and commanded with the help of a dynamically controlled pneumatic piston, described in the prevision chapter. This robot arm represents one of possibilities of implementing the made pneumatic piston.

Using the some principle, it was also done a three-finger hand, tri-orthogonally opposed, each finger being hyper redundant. It the made structure the three fingers are unitarily commanded, brut from the constructive point of view they con be independently

driven. Through pressure control it con be done the grip through finger coiling function or through the contact pressure of the fingers with the manipulated object. The made hyper redundant-finger hand was connected and commanded through the dynamically controlled pneumatic piston, described in the previous subchapter. This robot hand represents ohe of the possibilities of implementation of the made pneumatic piston.

The next subchapter deals with the control of a hyper redundant robot which uses the bending for gripping function. At first, it is studied the dynamic model for a hyper redundant arm which consists of continuous elements of flexible materials combined with actively controllable rheological elements. There are analyses problems of position control and power control. The difficulties given by the complexity of the integral-differential nonlinear equation are avoided through the system introduction of then energy – based relationships. The energy – based control laws are introduced in order to solve the position control. The proposed method for power control uses DSM C method for each evolution of the system in which it is controlled the viscosity of the rheological fluid, also using the numerical simulation.

In the last subchapter it is given a practical solution of making a hexapod mobile robot having hyper redundant legs with rheological fluid. The major advantage of this type of robot consists in the mobility of the legs which makes it ideal for a hilly ground, alluring movement without the central body balancing, lateral movements, spinning round the axis, so on. Some legs can also be used as manipulators. For this robot it was done a Visual Basic simulator for Auto CAD which allows the visual simulation of the robot movement depending on the independent command of the evolution of the legs.