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Investigations on the Dynamic Behavior of a Make-up Machine for Automation Purposes

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Abstract

The new developments in the oil and gas industry generate an increase demand of reliable threaded connections for the tubular goods. The reliability of such connections is based on the tribological properties of the thread compound used as a lubricant and sealant. A more advanced investigation of friction between the threaded components of tubular goods for the drilling and production operations is requested in order to better describe its behavior. In this context an automated testing facility should be able to apply controlled efforts on the threaded connections and to estimate the influences on the friction coefficient.
This paper describes the development and implementation of a simulator used for automatic control of all the necessary parameters of a dedicated make-up machine. The concept was simulated using MathLab and shows very good results. The focus of the investigations was the dynamic behavior of the system, the interaction of two control loops, and its response to external disturbances.

Key words*:* *make-up facility, simulation, interaction.*

Introduction

To date oil and gas industry requires a more advanced investigation of the friction which takes place inside of casing and tubing threaded connections. For this purpose special full scale testing facilities can be used in order to induce controlled efforts into threaded connections and to measure the made-up friction torque. By considering the physical properties of the tubulars and the qualities of the dope as well a customized facility for friction force investigation can be designed.

To simulate the make-up of a threaded connection we should apply a torque and an axial compression force on connection which will mimic the shoulder force. For the investigation the OCTG (Oil Country Tubular Good) connections the specimens are generalized as nut and bolt connections.

The friction coefficients are recommended by API (American Petroleum Institute) for standard dopes under usual conditions. In reality, the friction coefficient may deviate from recommendation due to special condition like extreme temperature and compound contamination (dust, drilling fluid, bio-material) [1].

The friction coefficient can be evaluated just in steady state combination of the angular speed and axial force. This requirement can be achieved by implementing an appropriate control of the make-up facility. The investigation of the dynamic behavior of the facility is required in order to better design the machine parameters and to compensate the disturbances.

The Functional Analysis of the Make-up Machine

The design of the make-up facility is divided in two blocks: the axial block and the rotational block. The most convenient method to apply the axial force is the utilization of a hydraulic cylinder. The force into cylinder is controlled by the hydraulic pressure in the actuating chamber. The cylinder force is mechanically transferred in the nut and bolt connection. The relative rotation between nut and bolt is generated by an electrical motor and transmitted by a gear box. The rotational system should assure a constant angular speed at specified set point.

Besides the enumerated functional objectives, the make-up facility must meet safety objectives for operator and overload. The actuators for the both sub-systems (axial and rotational) are presented in the figure 1.

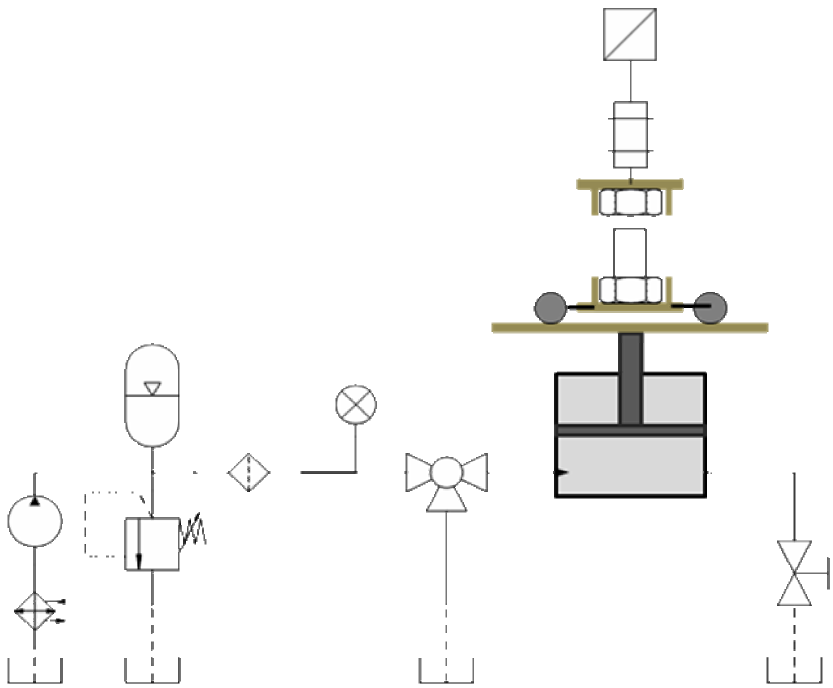

Fig. 1. The make-up machine components

The pressure into lower chamber is regulated by a tree-way control valve. The valve has as command an electrical tension of 0-10V. The pressure generator aggregate contains a fixed displacement pump which is generating a preload pressure for the tree-way valve. The control of the piston overloading is realized by a pressure relief vale. The pressure aggregate contains a hydraulic accumulator an oil cooler, and an oil filter.

The rotational sub-system is actuated by an AC motor connected to a frequency inverter.

The Interaction between the Make-up Machine Sub-systems

The figure 2 emphases the detailed diagram of the make-up machine subsystems.

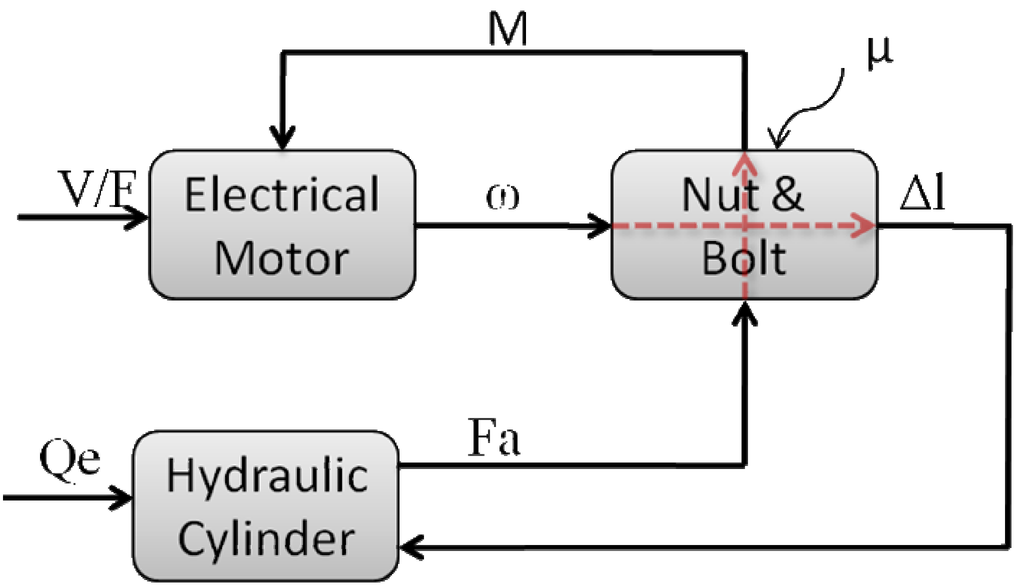

Fig. 2. The schematic of the make-up process.

The informational interconnections between blocs are traced by starting from the next assumptions:

- The friction force between nut and bolt is expressed by Coulomb friction law as product between the axial force and the friction coefficient which is considered constant during the experiment.
- The hydraulic piston is always in the contact with nut and bolt assembly
- The dynamic regime of the control valve is neglected.

In the figure 2 the axial actuator is represented by a hydraulic piston which filled by a oil inflow Qe. To rotate the nut the AC-motor receive a combination of tension frequency (V/F) from the static inverter.

The axial force generates proportional frictional torque M in the connection. This torque will increase the load of the electrical motor and as long the ratio V/F remains constant the angular velocity will decrease.

On the other side, the relative rotation of nut inside the bolt will cause the displacement of the hydraulic piston. If the oil inflow is not controlled, the axial force will decrease because of variation of the chamber volume.

Conform to the presented interactions can be said that every subsystem is introducing a disturbance effect in the second one.

The Simulator of the Make-up Process

To implement an appropriate control system for such make-up facility it is required a study of the steady state and dynamic behavior of the process. The automation can be tested offline on the process simulator. The software implementation of the simulator is based on SimHydraulics modules from Matlab [2].

The oil accumulation into variable volume chamber schema is presented in the figure 3.

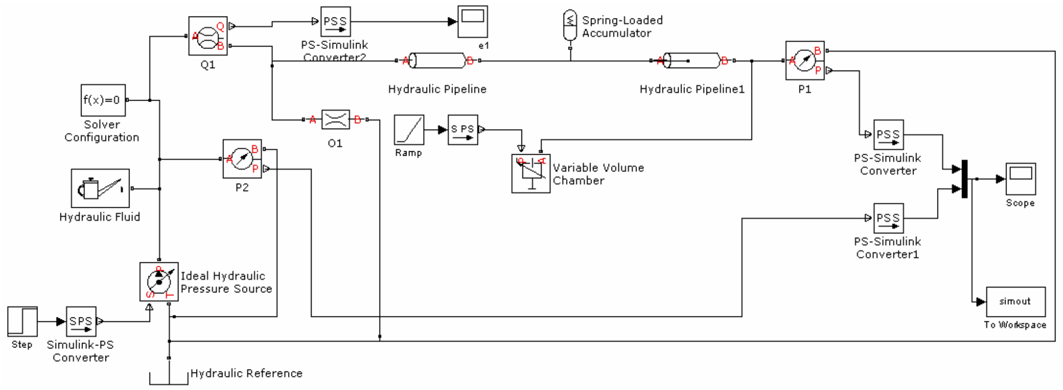

Fig. 3. The SimHyhraulics model for a variable chamber accumulation

The system is energized by an ideal pressure pump which incorporates the tank leakages O1 [3]. This obstruction is reducing the pump efficiency to 96%. The hydraulic fluid is transmitted by pipes with total length of 6m, with cross-section of 3mm and a roughness of 1,5*10-2mm. the pressure accumulator was designed to cut the pressure peaks from the piston pump and has a volume of 3 l. The figure 4 presents the pressure profile inside the cylinder chamber when the nut is rotating at maximum speed.

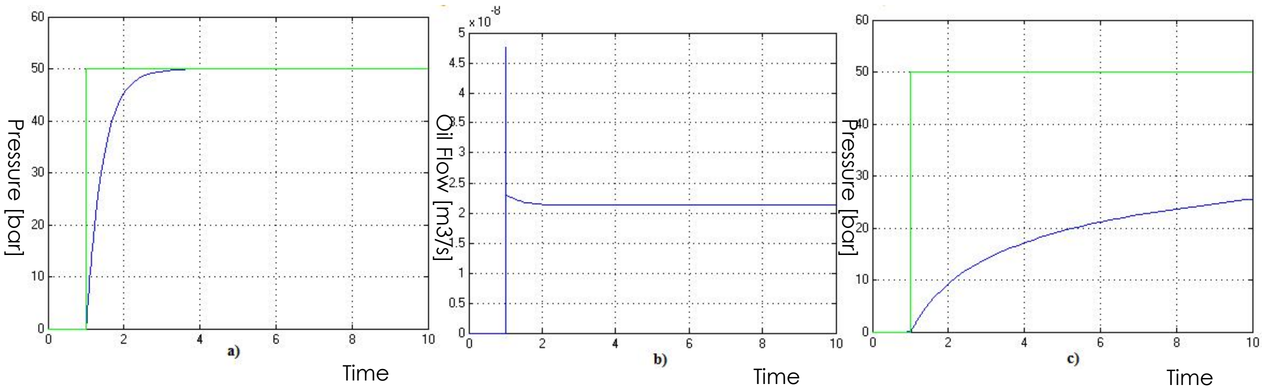

Fig. 4. The pressure dynamics in the variable volume chamber when the pressure is stepped and ramped up to 50 bars

The worst case is identified when the pressure and the rotation are applied simultaneous because the subsystems are passing together by transient regime. The flow diagram 4b shows that that the steady state flow volume of 2,2*10-8m3/s represents the maximal flow that the pump should provide. An exaggerated axial displacement of 10mm/s as in the figure 4c shows an insufficient flow in order to build the actuating pressure in the cylinder chamber.

The distributions on the axial subsystem are introduced by an ideal speed source. This module is simulating the relative axial movement between nut and bolt (see fig 5).

For the simulation of the axial subsystem is considered the next scenario:

- In time origin the control valve command is set to 25%
- After the system reaches the steady state regime a step signal of 0,1mm/s is applied to ideal speed generator

The simulation results are presented in the figure 6.

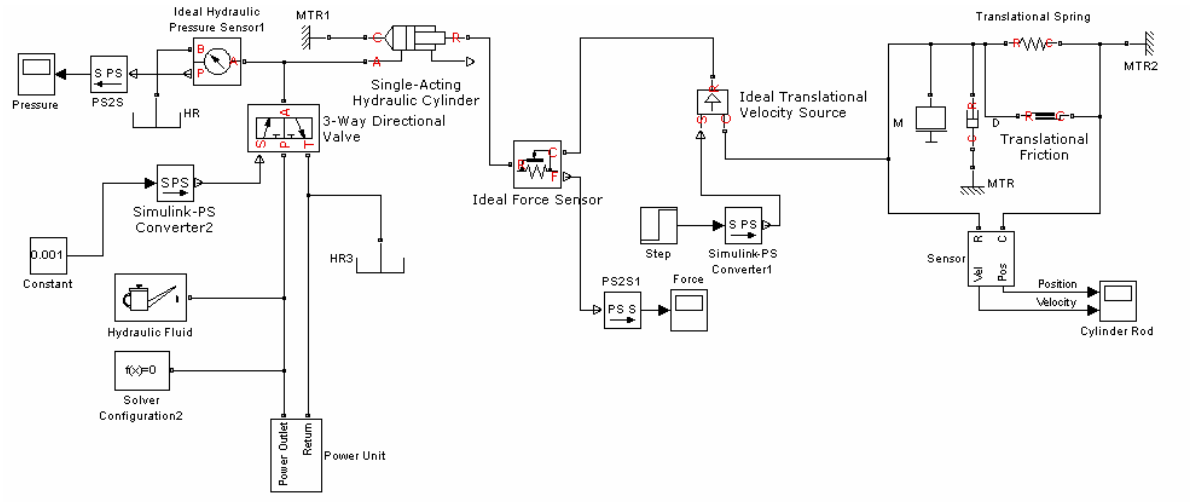

Fig. 5. The general model of the axial subsystem

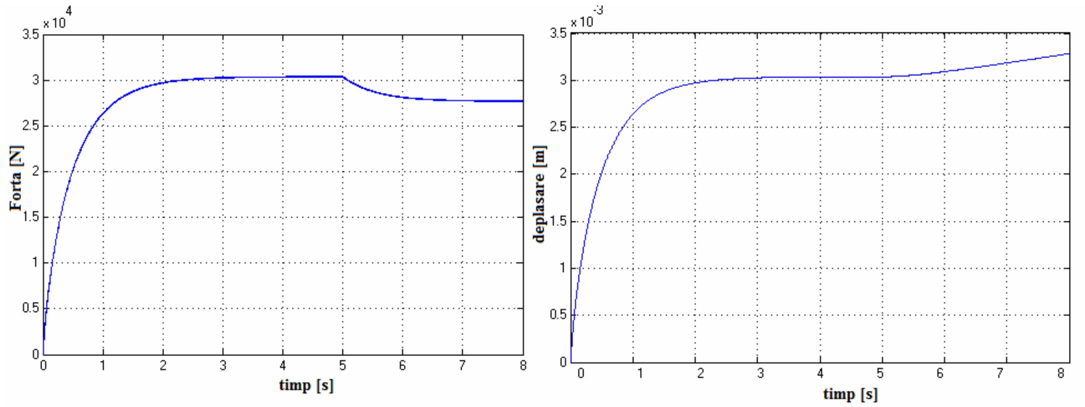

Fig. 6. The time evolution of the axial force in the nut and bolt assembly

The rotational system is actuated by a 750W electrical motor connected to a gear box. The motor torque can be calculated from the relation [4]:

$$P[W] = \frac{T[Nm] * \omega[RPM]}{9,5488} \tag{1}$$

In the considered case when the rotational speed is 5 RPM the torque is about 1,5kNm. This motor power is over dimensioned and can break the nut and bolt connection without speed to be affected. The dynamic regime of the rotational sub-system is presented in the figure 7.

By identification the rotational subsystem can be assimilated with a first order element with time constant of 0,5 sec conform to relation:

$$0,5\dot{y} + y = 0,57u \tag{2}$$

Conclusions

Because the actual recommendations do not define the dopes friction coefficient for special applications it is required to investigate in laboratory condition the friction force inside the threaded connection.

In this paper is presented the components and the interactions inside of a general make-up machine.
The simulations revealed that the selected components for the real machine are "just right" in case of the hydraulic unit and "over dimensioned" in case of the AC motor.

Based on the simulation results can be elaborated an adequate control for presented facility. However, the simulator shows the importance of accurate data acquisition and fast responding actuators.

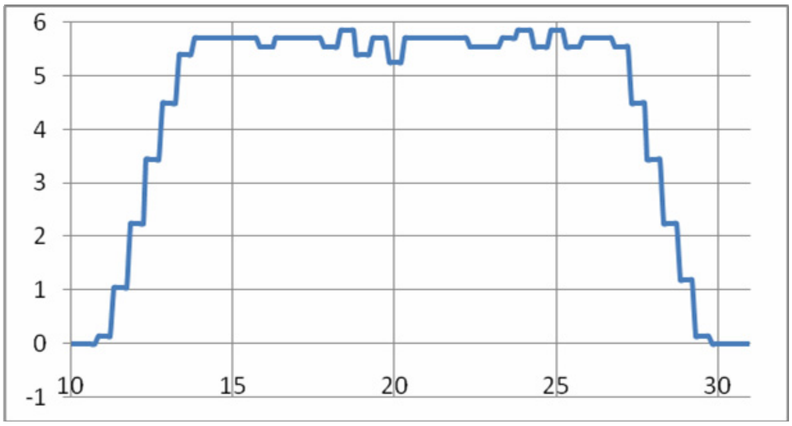

Fig. 7. The dynamic regime of the rotational subsystem

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Investigații privind comportarea dinamică a unei maşini de înşurubat în vederea automatizării

Rezumat

În momentul actual industria de petrol şi gaze necesită o investigație mai avansată a fricțiunii din componentele filetate ale tubulaturii utilizate în foraj şi extracție. În acest sens este necesar a se folosi instalații de testare capabile să inducă eforturi controlate în conexiunile filetate şi să măsoare influența acestora asupra forței de frecare la înşurubare. Considerând proprietățile fizice ale materialului tubular, precum şi calitățile mediatorului de ungere, se poate conceptualiza un sistem universal de înşurubare care să permită estimarea particularizată a forței de frecare. Această lucrare descrie dezvoltarea şi implementarea unui simulator ce este util in proiectarea controlului parametrilor unei maşini automate de înşurubat. Acest concept a fost simulat utilizând mediul Matlab/SimHydraulics generând cu bune rezultate. Investigația prezentată in acest articol se bazează pe interacțiunea sub-sistemelor componente ale maşinii de înşurubat.