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POSSIBILITIES OF CONTROL EXPERIMENTAL TESTING DEVICES FOR BIOMECHANICS

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Summary: *This paper describes our approach to control of the two types of experimental devices for biomechanics. First type of experimental device is the device for examining the spinal elements, device has three controlled axes. Second type is the device for testing of the wear of polyethylene cups with two controlled axes. All controlled axes are equipped with DC motor power drives. At the end of paper control units of the power drives are described.*

1. Introduction

Department of Biomechanics Institute of Solid Mechanics, Mechatronics and Biomechanics, Faculty of Mechanics Engineering, Brno University of Technology is dealing with experiments for the purpose of identifications of biomechanics materials past few years. For those experiments they are requiring special experimental devices. Experimental devices must be able to simulate movements of various parts of a human body as well as action force created during these motions. For this purpose two experimental devices had been designed and manufactured. First one is for examining the spinal elements and second one is for testing of the wear of polyethylene cups. In the year before last we (Laboratories of Mechatronics, jointed workplace of the IACS and IMSMB FME BUT and IT AS CR) had addressed in order to make control system of this device. The control system consists from control of the power drives and from making of the software for control and record of experiments.

2. Basic features of drives in term of control

The most important parameter for drives control is choice of the suitable sampling rate for sampling of rotation scanning. Rotation scanning by encoder proceeds in the following way: particular impulses in one channel are counted as they are coming, and meanwhile, according to the level of signal, we can distinguish the rotation direction. This way we get the current position of drive and we get the speed as the number of impulses at the beginning and at the

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end of defined time interval T_{IRC} (sampling period). Reciprocal of this time interval is sampling frequency of encoder f_{IRC}.

We search for such T_{IRC} that, at the minimal rotation speed, which will be still controlled, at least 2 impulses from IRC sensor would be counted. This condition is necessary for control of the motor rotation speed. The minimal controllable rotation speed is set according to required speed range of axe. All axes are required to have oscillating motion with sinusoidal wave of trajectory (cosine wave of speed). The controllable range of motor rotation speed will be, in both cases, the compromise between the choice T_{IRC} and accuracy of drive control. Sampling period is advisable to be the same at all drives to make the synchronizing of the drives easier and because of the similarity of delay errors at various drives [2].

For the accuracy of control, it would be suitable if the drive possibly worked at the rotation speed similar to the nominal ones. Furthermore, the term speed overdesign is introduced. It corresponds to the rate between nominal drive speed and maximum speed necessary for application. The higher this number is, the more difficult this drive is to control and it is too big and overdesigned. The angle of displacement and the frequency of movement were specified in [1].

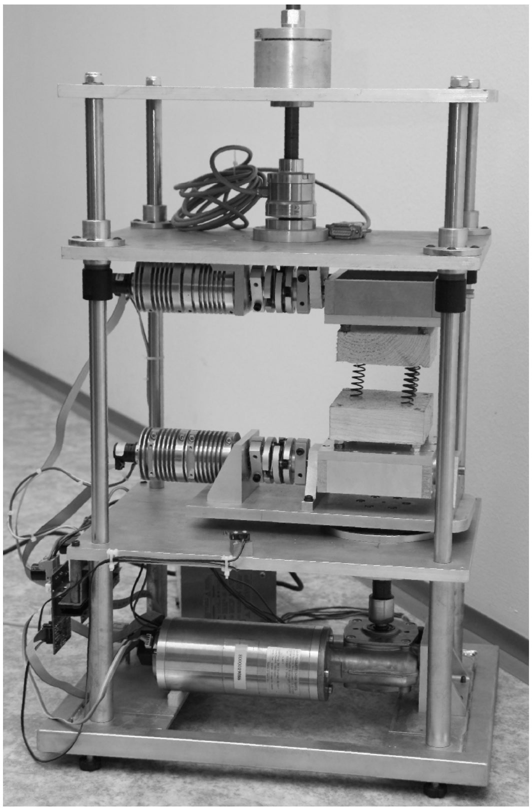

Fig. 1: Experimental device for examining the spinal elements

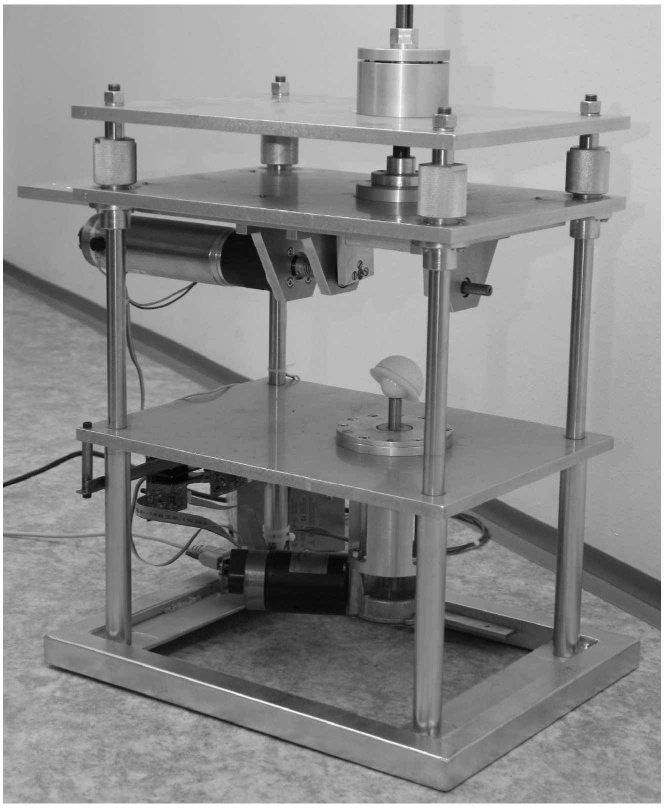

Fig. 2: Experimental device for testing of the wear of polyethylene cups

3. Experimental device for examining the spinal elements

A detailed description of the function of the device (fig. 1) is a part of [1]. The device was completed and tested in a trial run. During testing it was discovered that the gripping of a lower engine, which is used for excitation of torsion load of spinal element, is unsatisfactory. That is why this gripping was structurally adjusted and modified. Moreover, the connection between the engines, which cause the flexion on the device, and the cups was structurally adjusted. Such a modified device is now being tested in a trial run.

Electromechanical part of the experimental device for examining the spinal elements

Electromechanical part of the device contains three kinematic axes. Two axes of flexion (tab. 1) are equipped with the drives made by Portescap. Each of them consists of DC motor 28DT2R, a four-stages planetary gearhead R40 with gear ratio 478:1 and a three-channel incremental optical encoder E9 with resolution 100 counts per revolution.

The axe of torsion (tab. 2) is equipped with the drive made by KAG. It consists of DC motor of KAG type M80x80/I, worm-gearhead with gear ratio 80:1 and incremental optical encoder HEDS 5605/A13.

Tab. 1.: Drives of axes of flexion of the experimental device for examining the spinal elements

Required parameters	
displacement angle	±3 º
frequency of movement	0.5 Hz
maximal speed at gearhead output	0.0262 s^{-1}
Actual parameters of drive	
nominal motor speed	91.2 s^{-1}
gear ratio	478:1
nominal speed at gearhead output	0.214 s^{-1}
Parameters for control	
Speed overdesign	7.3x
minimal controllable speed at output from gearhead	0.00418 s^{-1}
T_{IRC}	10 ms
maximum operational speed of motor	12.5 s^{-1}
minimal controllable operational speed of motor	2 s^{-1}
maximum number of impulses encoder in T_{IRC}	13

Required process of displacement and velocity is shown in Fig. 3.

Drives Portescap are equipped with a standard gearhead with “standard” radial play (angle displacement of shaft) to 1º at load 0.3 Nm. At both drives there was measured the radial play 0.8º without load. The radial play on the gearhead output is 1/12 of operating range of axe and therefore it must be very well compensated by the control system. Nevertheless, it is impossible to foreclose random “error” caused by transition of the sample preloaded by loading over zero reversal point (Fig. 4).

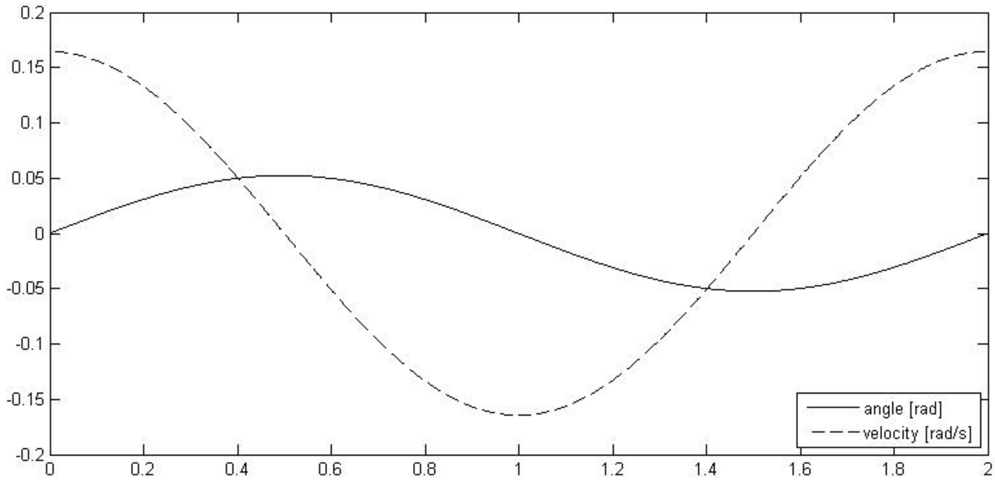

Fig. 3: Required process of displacement [rad] and velocity [rad/s^{-1}]

Sampling frequency does not meet the requirements for a good quality control. This problem is caused by mostly low resolution of encoders which were used. Nominal drive speed is 7.3x higher than maximum functional speed (maximum speed at gear output), which is the result of lower gear ratio of used gearheads.

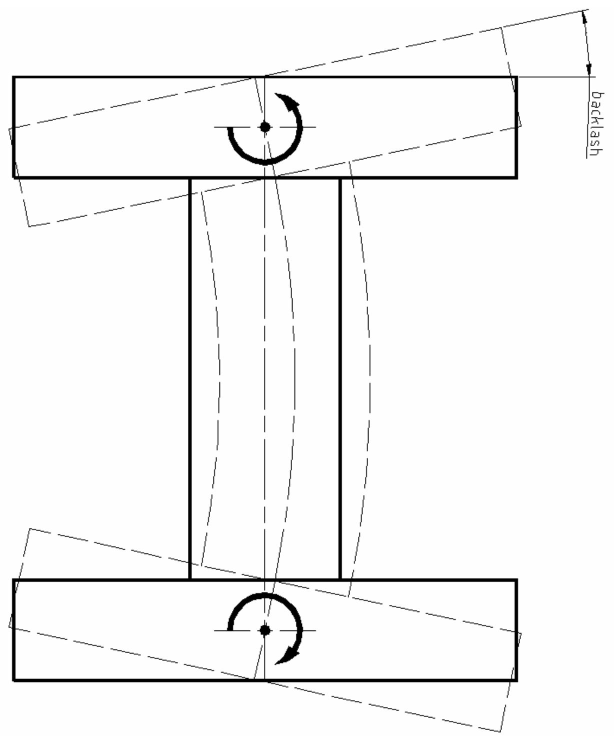

Fig. 4: Possible sample “error” at transition over zero reversal

During the experiments there also appeared the problem with slipping of frictional clutch used for moment transition from clutch to clamping cup. From the above-mentioned it is obvious that it is very difficult to control the axes, it means accomplishment of given parameters.

The requirements for movement of this drive are similar to those at axes of flexion.

Tab. 2.: Drive of torsion axe of the experimental device for examining the spinal elements

Required parameters	
displacement angle	±5 º
frequency of movement	0.5 Hz
maximal speed at gearhead output	0.0436 s^{-1}
Actual parameters of drive	
nominal motor speed	52.5 s^{-1}
gear ratio	80:1
nominal speed at gearhead output	0.656 s^{-1}
Parameters for control	
Speed overdesign	15x
minimal controllable speed at output from gearhead	0.005 s^{-1}
T_{IRC}	10 ms
maximum operational speed of motor	3.49 s^{-1}
minimal controllable operational speed of motor	2 s^{-1}
maximum number of impulses encoder in T_{IRC}	18

Speed overdesign of this drive is very big and the drive is practically impossible to control. Another problem is to specify sampling period T_{IRC}, which could be applicable to both types of drives.

Experiments and elimination of encountered drawbacks

The experiments with original construction confirmed the suspects stated above. The device is poorly controllable and the torsion axis is unstable because its operating speed is at the limits of capabilities of the applied drive. Moreover, the flexion axes showed problems with a slip of the friction clutches, which transmit moment from the gearhead to the clamping cups for sample attachment.

4. Innovated design of device for examining the spinal elements

It was decided on the grounds of this experience that the currently used drives would be replaced with the drives more suitable for the task. On the basis of market research Maxon drives were chosen for particular axes.

Parameters of the flexion axes are in (tab. 3) and parameters of the torsion axe are in (tab. 4). The speed overdesign 3.8x is for possibility of use higher frequency of movement 2Hz.

Tab. 3.: Drives of axes of flexion of the new experimental device for examining the spinal elements

Nominal values of motor RE 36	
nominal voltage	24 V
maximum continuous torque	0.0782 Nm
nominal speed	92.2 s-1
Values of gearbox GP42C	
maximum continuous torque	15 Nm
gear ratio	936:1
Encoder MR ENC type L	
counts per revolution	1024
number of channels	3
Operating parameters	
speed overdesign	3.8x
minimum controllable speed	0.001 s-1
T_{IRC}	2 ms
maximum operating speed of motor	24.5 s-1
minimum controllable operating speed of motor	0.977 s-1
maximum number of impulses encoder per T_{IRC}	51

Tab. 4.: Torsion axe of the new experimental device for examining the spinal elements

Nominal values of motor RE 36	
nominal voltage	24 V
maximum continuous torque	0.0782 Nm
nominal speed	92.2 s-1
Values of gearbox GP42C	
maximum continuous torque	15 Nm
gear ratio	546:1
Encoder MR ENC type L	
counts per revolution	1024
number of channels	3
Operating parameters	
speed overdesign	3.8x
minimum controllable speed	0.00179 s-1

T_{IRC}	2 ms
maximum operating speed of motor	23.8 s-1
minimum controllable operating speed of motor	0.977 s-1
maximum number of impulses encoder per T_{IRC}	51

Another design alteration of the device was a replacement of originally used friction clutches in the flexion axes with clutches transmitting the moment over a groove and tongue. The last design alteration of the device was a shifting of a force sensor measuring the sample load from the vertical central axis of the device to the vertical axis passing through the center of the clamping cups of the device. Thus altered, the device is capable of performing the required activity.

5. Experimental device for abrasion wear testing of polyethylene cups

Detailed description of the function of this device (Fig. 2) is included in [1]. The device has been assembled and it is currently being tested in a trial run.

The axis of rotation of the ceramic of the hip is set up (tab. 5) with a drive 403 930 from Valeo company. This drive by default comprises a DC motor SW2K with integrated worm gearhead with gear ratio 70:1 and a two-channel incremental optical encoder with resolution of 36 counts per revolution. The drive can be permanently loaded with torque of 2 Nm. The axis of oscillation of the acetabulum is set up (tab. 6) with a drive from Bonfiglioli company. This drive by default comprises a DC motor BCS 20 24 2700 and a planetary gearhead with a gear ratio 36:1.

Axis of rotation

Tab. 5: Axis of rotation of experimental device for abrasion wear testing of polyethylene cups

Required parameters	
angular displacement	±30°
motion frequency	1 Hz
maximum speed at gearhead output	0.523 s-1
Nominal values of Valeo 403 930 drive	
nominal drive speed	3.83 s-1
Operating parameters	
speed overdesign	7.3x
minimum controllable speed	0.0299 s-1
T_{IRC}	10 ms
maximum number of impulses encoder per T_{IRC}	46

An encoder with resolution of 36 counts per revolution which came with the used Valeo drive was replaced for operational needs with a HEDS-5500/A12 encoder with resolution of 500 counts per revolution.

The axis of oscillation

The used drive Bonfiglioli was supplemented with an IRC revolution sensor HEDS-5605/A13 with resolution of 500 counts per revolution.

Tab. 6.: Axis of oscillation of experimental device for abrasion wear testing of polyethylene cups

Required parameters	
angular displacement	±5°
motion frequency	1 Hz
maximum speed at gearhead output	0.0436 s^{-1}
Real parameters of Bonfiglioli drive	
nominal speed of motor	45 s^{-1}
gear ratio	36:1
nominal speed at gearhead output	1.25 s^{-1}
Operating parameters	
speed overdesign	14.3x
minimum controllable speed	0.4 s^{-1}
T_{IRC}	10 ms
maximum operating speed of motor	3.14 s^{-1}
minimum controllable operating speed of motor	0.4 s^{-1}
maximum number of impulses encoder per T_{IRC}	16

Both drives were putted into operation with T_{IRC} 10 ms. The device is putted into operation and is waiting for a sample supply and for specification of motions.

6. Control units of experimental devices drives

For the control of experimental devices drives described in previous chapters the control units developed within the project were used. These control units are provided with unified interface for the control of low-powered drives. The advantage of these units is primarily their capability of independent control of motion, velocities and acceleration along the more complex trajectory with defined synchronization points and their corresponding times. This enables to transmit the required trajectory to the control unit and subsequently only check the actual state, thus the superior synchronization level is considerably simplified. The unit is capable of the linear and circular interpolation of trajectory in accordance with entered parameters.

For the control of drives of the device a basic variant of control was used representing a classic cascade PID controller position – velocity – current [3]. The control units are controlled through standard serial interface. The integration into superior systems is enabled by a complex communication class incorporated in the .NET assembly. Due to the fact that the .Net assembly meets the international standard CLI (Common Language Infrastructure), standardized by international standardization committee ECMA [4], it is possible to use the class from any programming language or environment supporting this standard.

7. Conclusion

Experimental devices for biomechanical testing are described and analysed. New experimental testing device had been designed and manufactured upon located disadvantages (in collaboration with biomechanics). Both experimental devices for testing spinal elements and a one device for investigating wear of polyethylene cups are putted into the test operation. Functionality and reliability of experimental device will be verified during test operations period. Before putting into real operation devices must be equipped sensors for checking of actual absolute turning in all controlled axes.

The putted requirements on the new testing device are fulfilled better than the original one. The original experimental device for examining the spinal elements will be used for software testing during the development. Our goal is putt experimental devices into real operation over this year.

Acknowledgement

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