The Compare of Several Variants of Flexible Members with Electromagnetic Elements for Robots with Variable Joint Stiffness

P.Beneš, J.Fořt and M. Pittermann[1]

***Abstract* —** The article presented two proposals for construction of a flexible element with variable stiffness, in which construction is limited, or is it completely eliminated the mechanical elastic member such as spring. Their properties vary in the extent applicable member stiffness and speed of reaction to contact with an obstacle. By limiting, or eliminating the mechanical elastic member can be achieved by increasing the life of the flexible joint.

***Keywords*—**joint stiffness, safety of robots, electric drive for robots.

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I. INTRODUCTION

THE assurance of safety in the field of the collaboration of robots with humans is now one of the most actual problems. Motivation of this exertion is to bring near the function of robots to humans activities. Typical examples are the co-operation with human in dangerous ambient, or assistance to disabled human. Standard industry robots are inadvisable, because they have outsize value of torque and value of inertia of its parts. This is why the big care was consecrate to problematic of safety of robots in the next years.

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II. THE SAFETY

On the issue of improving security in cooperation with the robot man can be accessed in several ways. The new generation of lightweight (LWR) robots are developed, compared to conventional industrial robots to increase their effectiveness, agility, and simplify the handling.

Secure interaction with the environment and especially with people in these robots ensure effective sensory systems and reducing the inertia of the system using special composite materials. The sensors provide feedback to both internal and focused on the regulation of the robotic system drives, and external feedback to allow positional oriented adaptivity effector contact with the environment.

The disadvantage of these robotic systems is their price, which rises sharply by using composite materials and high performance sensors and actuators.

Another option to ensure safe interaction robotic system with the environment is an approximation of stiffness joint stiffness of the robotic system to interface to the robot and the environment. Use of variable stiffness of the robotic system meets all the requirements for precise and safe robot interaction with an unknown man and environment.

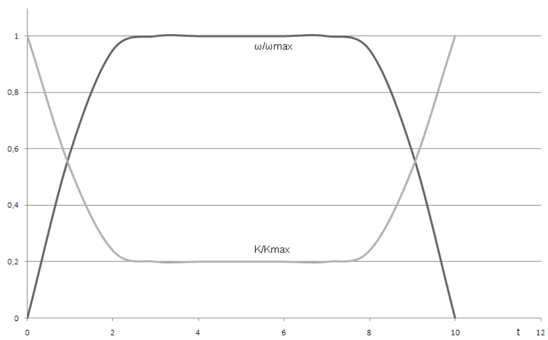


Fig. 2.1 Trajectories of joint velocity and stiffness

III. FLEXIBLE JOINT

Flexible joints with adjustable stiffness settings allow the robotic system stiffness depending on the speed of effector, where the velocity decreases with increasing stiffness of the robotic system. The development of these joints is currently one of the trends in robotics. In addition, the already mentioned ensure safe robot-human collaboration are utilized also for robotic prostheses, rehabilitation robotic systems, walking robots, etc.

The function of the first type is shown in Figure 3.1. The drive shaft is fixed positioned electromagnet flexible member. Arm robotic system is attached to the shaft via a rotary bearing. In the body of the robot arm is coil, which creates an electromagnetic field. A magnet placed in the field is maintained at a constant position by force directly proportional to the intensity of electromagnetic fields

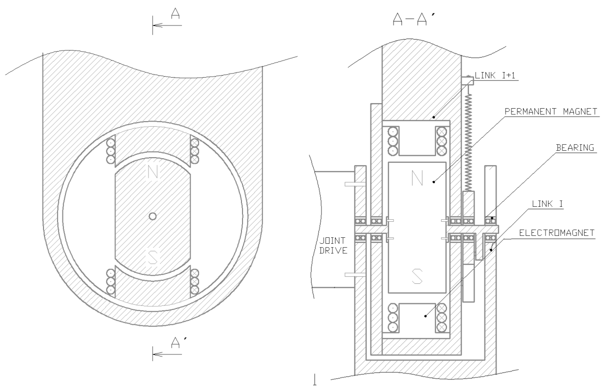


Fig. 3.1 First type of joint (electromagnetic flexible joint)

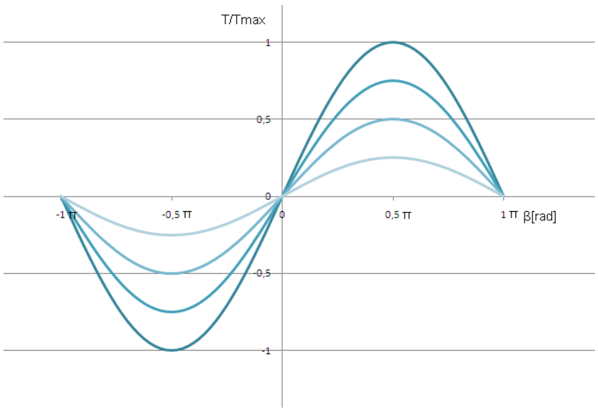


Fig.3.2 Graph of Torque Vs Angle of first type of joint without auxiliary mechanical flexible member

Basic chart curve of the size of the drive torque, depending on the angle of rotation of the magnet towards the link of the robot under ideal conditions is a sine wave. Much of this characteristic is almost linear. When the angle of rotation, in which chart curve ceases to be linear, let us call it point nonlinearities, there is a flexible mechanical connection member, starting participate in the creation of stiffness joint.

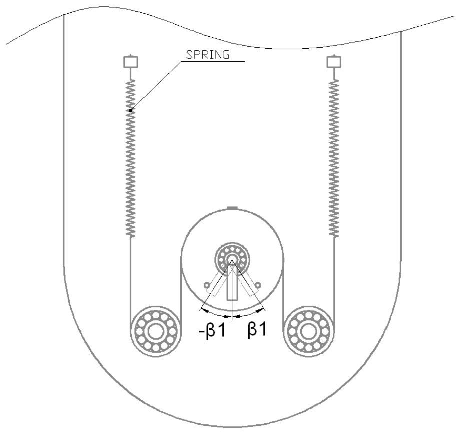


Fig. 3.3 Auxiliary mechanical flexible member

When you reach a point of nonlinearity is to increase stiffness of the equivalent stiffness of the material stops the sum of the electromagnetic coupling stiffness.

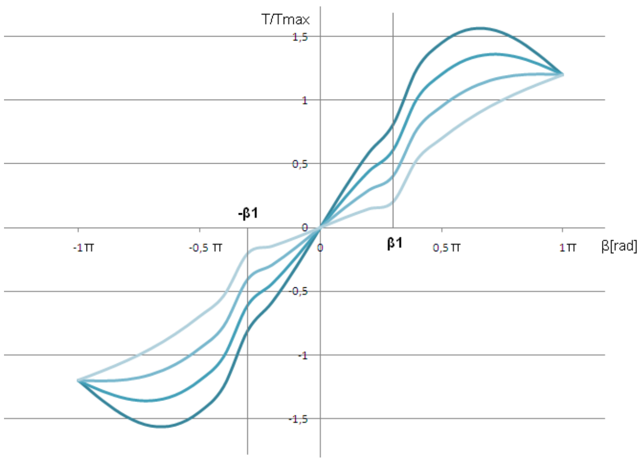


Fig. 3.4 Graph of Torque Vs Angle of first type of joint without auxiliary mechanical flexible member

In order to achieve maximum stiffness joint robotic system is equipped with electromagnetic brake. The effect of the brakes, this flexible joint becomes fixed mechanical linkage.

The advantage described structure with variable stiffness (compared to flexible mechanical joint) is a higher rate of change of stiffness and minimizing stress on the mechanical elastic member. This member is (compared with the mechanical elastic members) connected only when crossing point nonlinearities.

The disadvantage of this type of joint is relatively lower maximum steering stiffness. Thus the possibility of using this type of joint is limited.

Increasing the maximum controllable stiffness can be achieved using a second type of flexible joint, from whose structures are flexible mechanical parts completely excluded.

Drive shaft joint is fixed to the shaft EC motor with its own gear-box. Gear ratio of this gear-box is lower than the gear ratio of gear-box main drive.

To control the motor will be used by the regulation shaft position to be included in current limit. This will ensure the desired torque setting on the gearbox shaft and thus the required stiffness of the flexible joint.

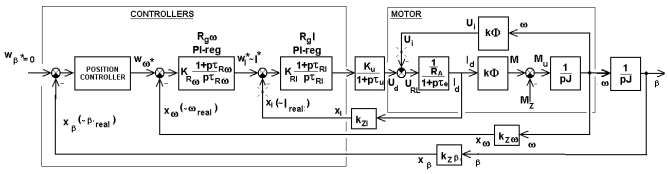


Fig. 3.5 A block diagram of controller

When the request to reduce the stiffness of the joint, system is reduced torque, which is held by the motor shaft in the basic position

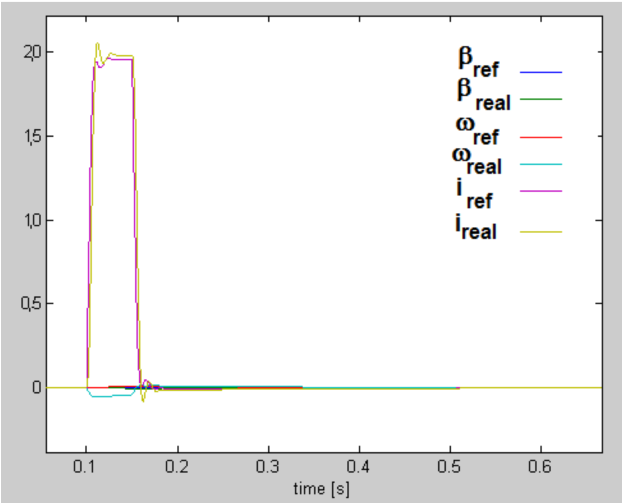


Fig. 3.6 Time chart of regulation loop

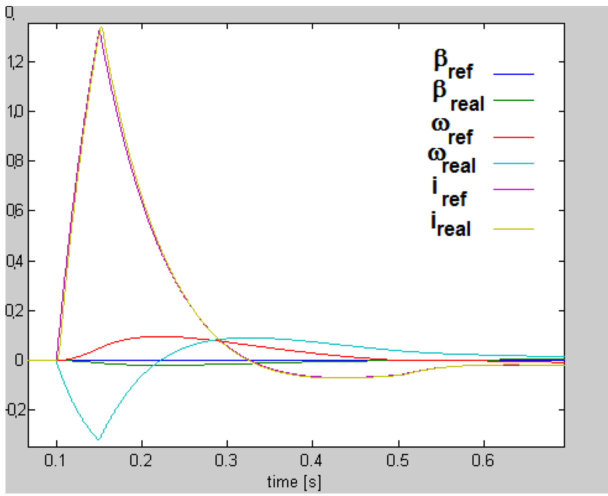


Fig. 3.7 Time chart of regulation loop with faulty controllers parameters.

Increasing the range of stiffness using gear box here leads to slow reaction to contact with an obstacle. This problem may not be limiting, since the reaction must be at least comparable with the maximum speed effector. This condition can be fulfilled.

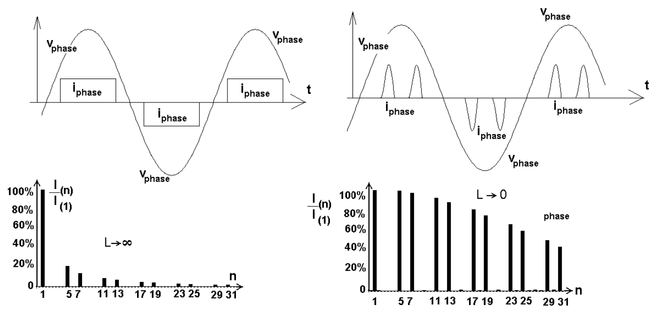
The chart curve (stiffness vs angle of this described elastic joint) is dependent on the selected control algorithm of EC motor flexible member. This chart curve is also slightly influenced by flexible stiffness of the gear member. When using the higher quality gear, however, this effect due to the overall stiffness of the system is negligible.

To achieve the maximum possible stiffness will again be flexible member equipped with electromagnetic brake, which can completely to block the function of flexible member.

APPENDIX

Very important is also the issue of the impact on power supply network - for example, in case if there is a high performance drive or if it is installed large quantity of such type of drive. Although observed so far for the type of drive cannot yet consider it a crucial aspect, there are displayed the current waveform drawn from the power grid. Fig A.1a current waveform is assumed ideally smooth (for using a large inductance). Fig A.1b expected current waveform significantly crimped (for using a small inductance).

Figure A.1 also shows a comparison of the content of higher harmonics in the current phase of the network.



a) Large inductance b)Small inductance

Fig. A.1 Input current from power grid

REFERENCES

[1] A. De Luca, R. Farina, and P. Lucibello, “On the control of robots with visco-elastic joints,” in Proc. IEEE Int. Conf. on Robotics and Automation, 2005, pp. 4297–4302.

[2] D. Wilson, G. Starr, G. Parker, and R. Robinett, “Robust control design for flexible-link/flexible-joint robots,” in Proc. of the IEEE Int. Conf. on Robotics and Automation, 2000.

[3] A. De Luca, “Feedforward/feedback laws for the control of flexible robots,” in Proc. of the IEEE Int. Conf. on Robotics and Automation, 2000, pp. 233–240.

[4] A. De Luca and P. Lucibello, “A general algorithm for dynamic feedback linearization of robots with elastic joints,” in Proc. IEEE Int. Conf. on Robotics and Automation, 1998.

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[5] A. De Luca, "Dynamic control of robots with joint elasticity," in Proc. IEEE Int. Conf. on Robotics and Automation, 1988.
[6] G. Palli, C. Melchiorri, and A. De Luca, "On the feedback linearization of robots with variable joint stiffness," in Proc. of the IEEE Int. Conf. on Robotics and Automation, 2008.
[7] T. Wimbock, C. Ott, A. Albu-Schaffer, A. Kugi, and G. Hirzinger, "Impedance control for variable stiffness mechanisms with nonlinear joint coupling," in Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, 2008.
[8] A. De Luca, A. Albu-Sch¨affer, S. Haddadin, and G. Hirzinger, "Collision detection and safe reaction with the DLR-III lightweight manipulator arm," in Proc. of the 2006 IEEE Int. Conf. on Intelligent Robots and Systems, Beijing, China, October 9-15 2006, pp. 1623–1630.
[9] S. Haddadin, A. Albu-Schaffer, A. De Luca, and G. Hirzinger, "Collision detection and reaction: A contribution to safe physical humanrobot interaction," in Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, 2008.
[10] G. Tonietti, R. Schiavi, and A. Bicchi, "Design and control of a variable stiffness actuator for safe and fast physical human/robot interaction," in Proc. IEEE Int. Conf. on Robotics and Automation, 2005.
[11] A. Bicchi, S. L. Rizzini, and G. Tonietti, "Compliant design for intrinsic safety: General issue and preliminary design," in Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, 2001.
[12] Olsen, M.M. and H.G. Peterson, A New Method for Estimating Parameters of a Dynamic Robot Model. IEEE Transactions on Robotics and Automation, 2001. 17(1): p. 95-100.
[13] M.W. Spong \Modeling and Control of Elastic Joint Robots", IEEE Journal of Robotics and Automation, Vol. RA-3, No.4, pp. 291-300, 1987.
[14] H. Blaya and J. A. Herr, ''Adaptive control of a variable-impedance ankle-foot orthosis to assist drop-foot gait,'' IEEE Trans. Neural Syst. Rehabil. Eng., vol. 12, no. 1, pp. 24–31, Mar. 2004.
[15] A. Bicchi and G. Tonietti, ''Fast and soft arm tactics: Dealing with the safety-performance trade-off in robot arms design and control,'' IEEE Robot. Automat. Mag., vol. 11, no. 2, pp. 22–33, 2004.
[16] S. Au, J. Weber, and H. Herr, ''Biomechanical design of a powered ankle-foot prosthesis,'' in Proc. IEEE 10th Int. Conf. Rehabilitation Robotics (ICORR'07), June 2007, pp. 298–303.
[17] C. English and D. Russell, ''Mechanics and stiffness limitations of a variable stiffness actuator for use in prosthetic limbs,'' Mechanism Mach.Theor., vol. 34, no. 1, pp. 7–25, Jan. 1999.

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