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Grippers for adaptive robotic assembly.

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ABSTRACT.

In the preparation for robotic assembly variety of experiments was performed, examining relation between the gripper stiffness and its passive adaptivity. The basic couples nut-bolt, pin-hole and spline-keyseat are supposed to be elementar operations in assembly technology and are dealed separately. The conclusions are drawn for the gripper construction and the scope of active and passive gripper application is settled. The active gripper construction is introduced.

INTRODUCTION.

Facing the problem of robotic assembly in the situation of nearly no information about experience and skill in this branch, we decided to begin from the very beginning.

It is clear that the visual system has to be used, allowing to discriminate among several details and chosing the proper one to be picked up, and specifying its position and orientation. Nevertheless, such a system alone is not able to perform the function properly, due to its limits of discrimination ability (the picture element finite dimensions). Inaccuracy of end effector positioning, typically .1 till end effector, in the smaller or greater extent, has to deal with this principal inaccuracy. This can be done in the passive way, with some general algorithmus of seeking the proper position, or in the active way, with the use of sensors built in the robotic gripper, which can obtain the information about the relative position of both components to be joined together. The questions we wanted to answer by the experiment were: What can be performed with sensorless gripper? What is the optimal trajectory of the proper position seeking? What is the relevant information for shortening the time requirement for the operation? Is it possible to recommend some minor shape changes of standard components, which can make the operation easier?

We decided to examine three basic assembly problems characterised by doubles nut-bolt, pin-hole and spline-keyseat. Another simpification of our task was the assumption, one of the components is fixed to the base (in the coordinate system), and the other one is moving. We used the passive gripper with mechanical draw-back type spring collet with pneumatic drive as it was the only disposable gripper in this very moment, obviously far from being ideal one for our task. Similarly, the robot used for experiments was Czechoslovak APR-20 (adaptive industrial robot with load up to 20 kg, electric drives, angular kinematic system), programmable in RAMAS language. It was not suitable not only because of its poor m.t.b.f. approx. 45 hours. Its description is of no use for any reader. As we worked with sensorless gripper, we used "hard programmed" robotic motion, without adaptivity. We intended to use our experience to construct grippers able to perform the task reliably.

NUT - BOLT DOUBLE.

Experiments were performed with standard bolt with hexagonal head, diameter M8, M12, M14. As a displacement to be corrected by proper algorithm, value e = 1.5 mm was chosen. (Hence, it was necessary to seek the proper position in the area k x k, where k = 2e.) This corresponds to a simple and cheap vision system, 256x256 pixels, and the dimension approximately 400x400 mm of visible field. We assumed that if the chosen seek algorithm fills the task for displacement e, then it is sufficient for any displacement $d \leq e$ (assumption A). Coincidence of both axes (or the position close to it, allowing the bolt to be inserted into the nut) is indicated by axial shift of the head. A simple microswitch provides flag signal. At the beginning of seek movement both axes have the same direction (for instance by "tool mode" in VAL II language).

Full screw algorithm follows:

1) Set the calculated end effector position (point C).

2) Perform the seek motion untill FLAG = 1 (see below).

3) Turn the bolt for 2π anticlockwise (to set its proper position in the nut) under the slight axial force. FLAG = 0.

4) Turn the bolt clockwise until adjusted value of torque moment is reached.

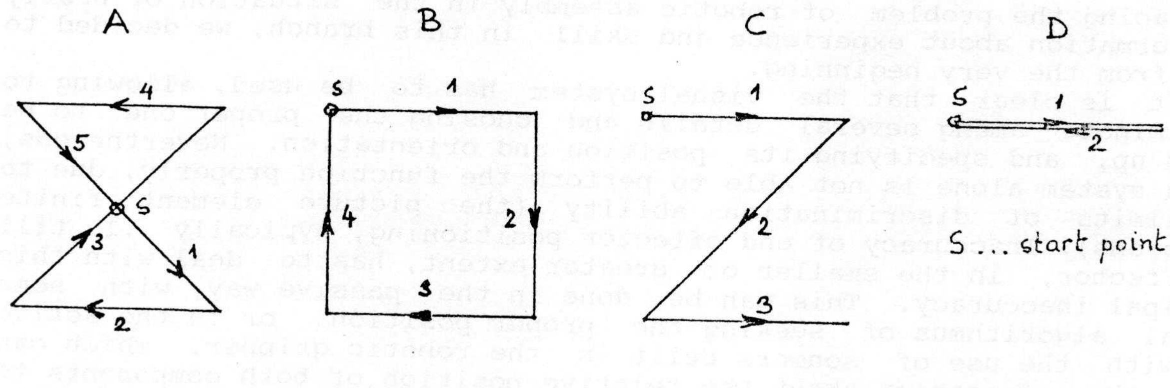

Fig. 1 Seek trajectories.

Several seek trajectories were examined (Fig.1). Experiments were repeatedly performed varying starting point across the error field (Fig.2). It was proven that assumption (A) is correct.

Subsequently, the relation of k = 2e upon the bolt diameter was tested. It is possible to say that the optimal choice of error region dimension can shorten the operation. As the experiments show, k = 3 mm was good value for the bolt diameter range M8 till M14 we used. For the smaller diameters, say M10 and less, k = 2 mm was sufficient choice. Another way to fasten the operation is the proper seek trajectory application. Path A is universal,but slow, and we can recommend it for small bolt diameters M3 till M6. Path B is faster and fully convenient for M6 plus bolts. For the big bolts, M12 and more, even the simplest paths C, D can be applied.

We suppose that the conclusions to gripper construction represent the main value of our work. Anyhow, we apologise to everybody to whom this sounds well-known or naive.

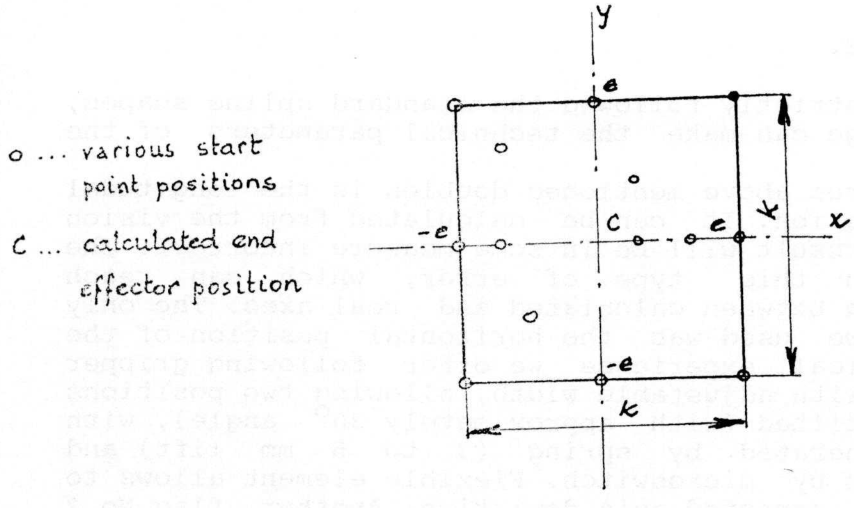

Fig. 2 Error (displacement) field.

1) Stiff or rigid gripper cannot perform bolt-nut screwing. At least, mechanical clearance is necessary to allow fitting proper position of one component towards another one. For big bolts, say, M12+, passive gripper is sufficient, if the demands for exact screw torque moment are not eliminated by flexible element. In such a case, mechanical lock is to be used, eliminating the flexible element after the measurement phase.

2) Gripper has to be furnished by a spring generating an axial force pushing bolt towards the nut, and a microswitch indicating that the bolt was inserted into the nut hole (axial shift), i.e. flag signalisation.

3) Gripper has to be equipped by the motor driving bolt screwing in both directions. If various bolt types application are supposed, exchangeable head would be usefull (outer or inner hexagonal head of various dimensions, simple screwdriver head, etc.). Adjustable torque moment clutch is necessary.

4) Bolt slideway has to be performed by spring-collet type holders in high demand applications, or with quasi-parallel V-shaped holders in cheaper conditions.

5) Active grippers with sensors can fasten the operation,and they are recommended especially if bolts of small diameters are used. Probably optrons or tensometers would be the right choice of sensor type.

PIN - HOLE DOUBLE.

Experiments were performed with cylindical pin ϕ 8 and ϕ 12, length 63 mm. This task is very similar to the previous one, but it is more sensitive to the reduction of the step k. Probably it depends on the different shape of pin end. We were succesfull till the push fit, and close running fit. Drive fit needs a special head. In the last case gripper with sensors for proper pin position setting seems to be necessary.

Recommendation for gripper construction: chuck collet type holding is to be used, with ability to produce greater forces for pin holding, than in the case of bolt manipulation. Trajectory B among the seek paths is the most suitable. If the deviation from the standard pin shape is allowed, we recommend 2 mm edge bevelling under the 45° angle. In such a case, the step k can be lowered with growing pin diameter.

SPLINE - KEYSEAT DOUBLE.

In this case we have strictly followed the standard spline shapes, as we felt any shape change can make the technical parameters of the connection less reliable.

The first difference from above mentioned doubles is the longitudal spline and keyseat orientation. It can be calculated from the vision system data, and again the result will be in some measure incorrect. The gripper has to cope with this type of error, which can reach approximately 10° deviation between calculated and real axes. The only experiment simplification we used was the horizontal position of the keyseat. After some practical experience we offer following gripper arrangement: parallel jaws with adjustable width, allowing two positions - basic (horizontal) and tilted (with approximately 30° angle), with slight vertical force generated by spring (3 to 5 mm lift) and indication of lower position by microswitch. Flexible element allows to turn jaws in the extent of expected axis deviation. Another flag No 2 (microswitch) indicates the stop of the longi- tudinal shift. Then we used following algorithm to join both elements:

1/ Seize the spline into the gripper in half of the heigth.

2/ Calculate position and orientation of both spline and keyseat and transport the spline above keyseat, both axes parallel, the lower end of spline above the center of keyseat.

3/ Tilt the spline in the jaws, and shift low untill FLAG = 1. Flag indicates vertikal jaw shift against the spring force, generated by mutual contact of both components.

4/ Move perpendiculary to the axis untill FLAG = 0, i.e. lower end of the spline fits in the keyseat.

5/ Shift the spline along the axis towards the lower end untill the spline reaches the edge of the keyseat (FLAG2 = 1).

6/ Push the upper end of the spline to fit in the keyseat. push the lower end into the keyseat too.

An algorithm and gripper principle are illustrated at the Fig.3.

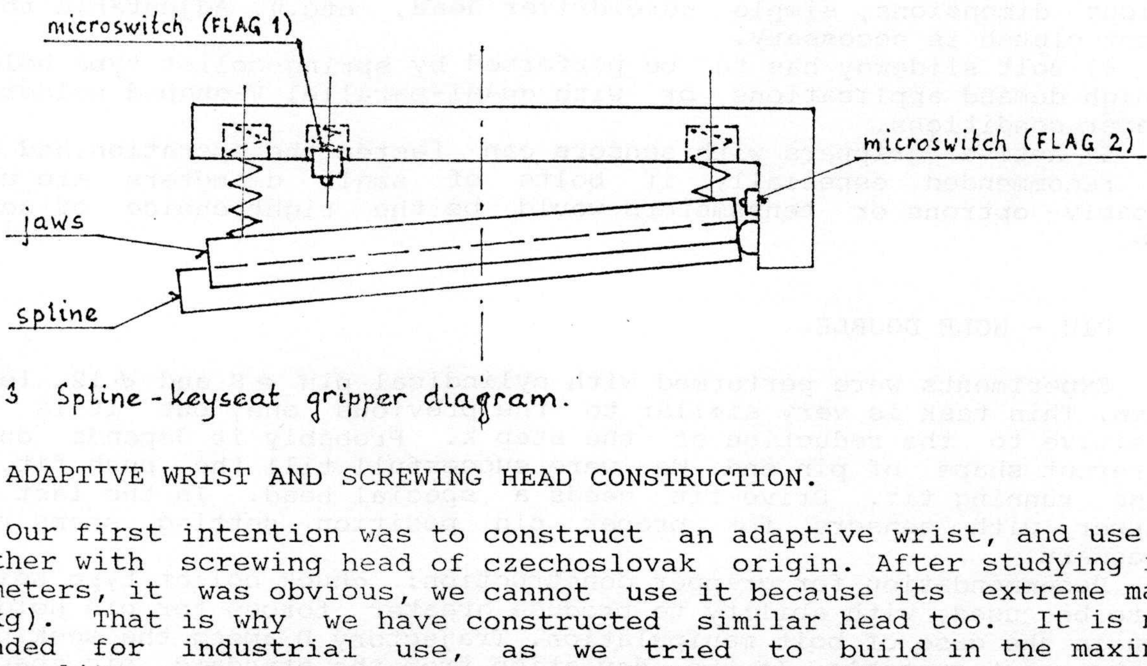

Fig. 3 Spline - keyseat gripper diagram.

ADAPTIVE WRIST AND SCREWING HEAD CONSTRUCTION.

Our first intention was to construct an adaptive wrist, and use it together with screwing head of czechoslovak origin. After studying its parameters, it was obvious, we cannot use it because its extreme mass (12 kg). That is why we have constructed similar head too. It is not intended for industrial use, as we tried to build in the maximal universality, and the result is again bulky. Nevertheless, we expect,

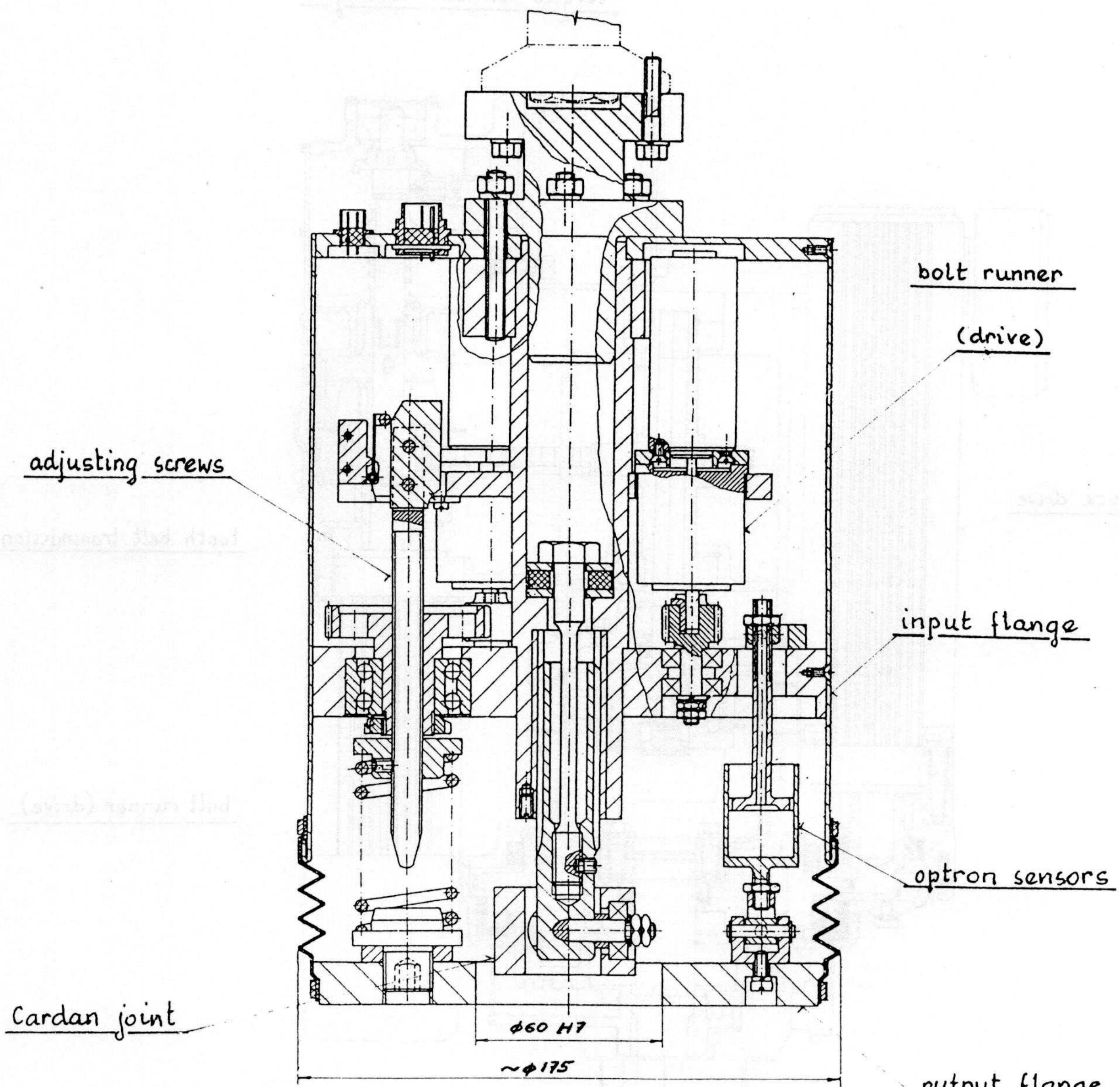

Fig. 4 Adaptive wrist construction.

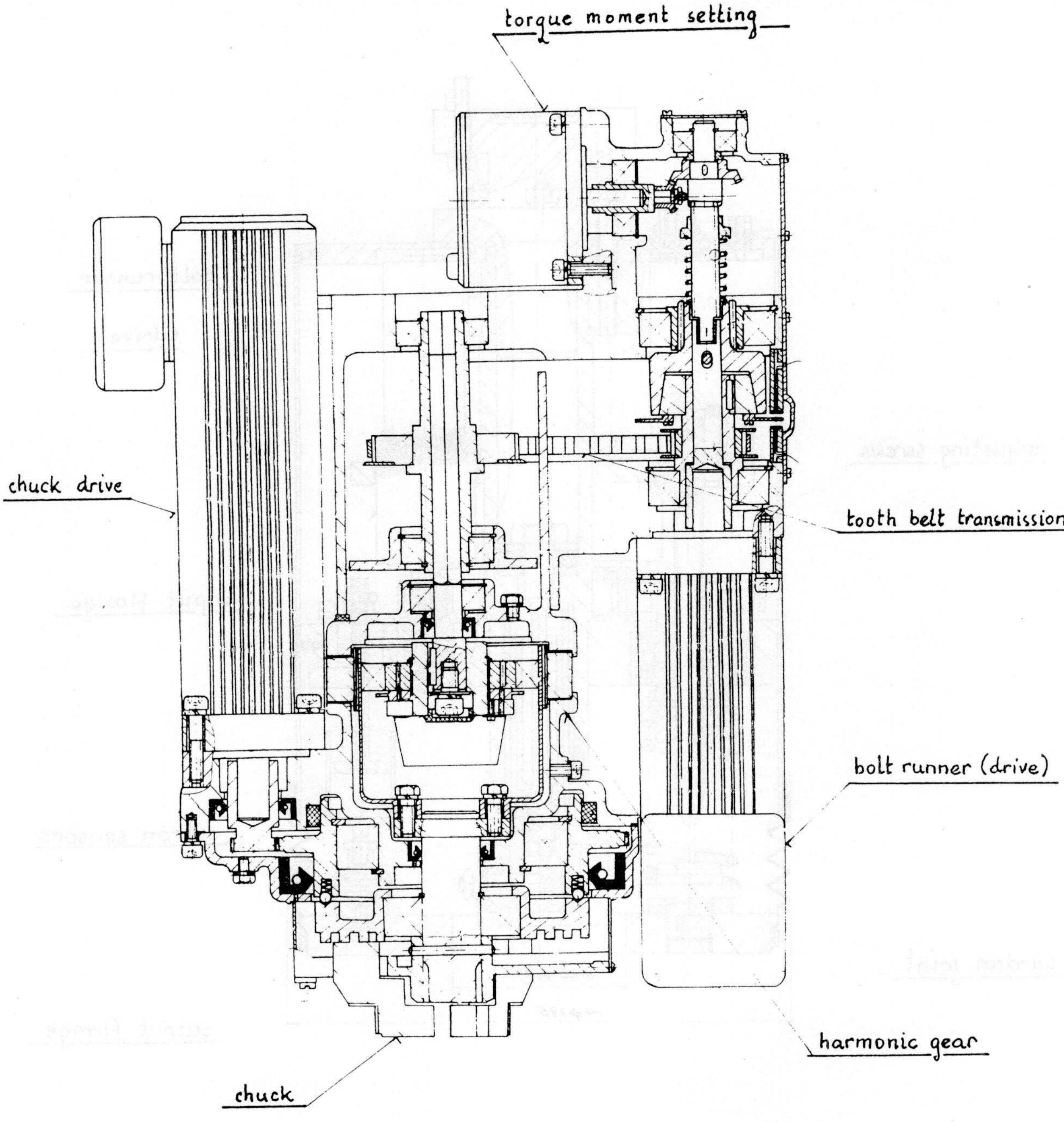

Fig. 5 Screwing head construction.

further experiments will allow to gain the skill necessary to construct a "tailor suited" gripper, which can be optimized according the real demands.

The wrist enables not only to find qickly proper axial position of the bolt towards the nut, but to compensate the gravi- tational force effect in the case of horizontal screwing.

The wrist (Fig.4) consists from following parts:two parallel circular flanges are joined together with 4 strong springs. One of them is fastened to the robot arm, another one carries end effector. Against the spring force 4 pins can adjust the base position as a result of 4 motor activity. Information about mutual position of both flanges bring 4 optrons, able to discriminate .1 mm displacement. A shaft with Cardan joint, going along the axis, allows to tilt the lower basis for approximately 15^{o}, and does not loose ability to transfer the torque moment. The joint is situated in the plane of spring clamping, and this position allows to simplify the deflection calculations. An axial shift is indicated by microswitch (flag). If the vertical work position is required only, a simplified version without motor can be used.

The screw head is mounted to the wrist. It has three-jawed chuck for holding the bolt with hexagonal head of various dimensions, a motor generating the jaw force, an axial shift indication by microswitch, electric drive allowing bolt rotation in both directions, friction safety clutch uncoupling both shafts at the adjusted value of the torque moment, step motor for value setting of the torque moment.The head mass is approximately 8 kg. Substantial mass reduction of the end effector, which would be very welcomed, is possible by integrating the sensor system into the screwing head. Such a construction is prepared by our students in their this year diploma thesis.

FINAL NOTES.

In this moment the wrist and the head are materialized, and we hope we shall be able to bring the results of experiments to the Conference session.

ACKNOWLEDGEMENT.

We want to express our gratitude to the students of the department of work machines and industrial robots, who performed the substantial part of experimental and/or construction work. Their names are listed in References.

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