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INTRODUCTION OF INDUSTRIAL ROBOTS ON SURFACE PROTECTION JOBS IN SHIPYARDS

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ABSTRACT

The great participation of direct human work characterizes today's shipbuilding industry. The actual status in development of science and technology makes possible the replacement of humans with industrial robots in a great number of these working places.

The strategy of industrial robots introduction in shipyards has to be adapted to existing working conditions, and introduction has to be done gradually.

The paper deals with a new method for priority setting of industrial robots working places and structures in shipyards, based on the Analytic Hierarchy Process. The numerical measure of priority of working places is based on the comparative pairwise judgments of social,psychological, technological, technical, safety, productivity and economical factors on different working locations. After the priority working places and priority working operations are chosen, the priority structures of adequate industrial robots are suggested according to their geometric, kinematic, dynamic and control characteristics.

KEY WORDS: Industrial robots, shipuilding industry, priority setting, Analytic Hierarchy Process.

1. INTRODUCTION

The use of industrial robots in production operations is a relatively new aspect of manufacturing engineering. The development and implementation of robots applications generally follows the same basic sequence as any other manufacturing process. However, the robot's unique combinations requires some special considerations for succesful application.

The use of industrial robots in shipbuilding industry is a quite new aspect, so there is not much experience from this field and existing data are very poor and unattainable |1,2,3|.

Today's shipbuilding industry is characterized with great participation of direct human work on hard, dangerous and fatiguing jobs. The actual status in development of science and technology makes possible the replacement of humans with industrial robots or with other automatic machines in a great number of these working places. The operations of surface cleaning, surface protection, coating, painting and welding are surely the operations which can be succesfully done by today's industrial robots.

The strategy of industrial robot introduction in shipyards has to be adapted to existing working conditions, and intruduction has to be done gradually. The experience from other fields | 4 | confirms that the first robot installed at any location is the most important, and this fact was our motto throughout entire project and investigation. Our efforts in this project was oriented in these directions:
- to become thoroughly familiar with working locations and operations,
- to include workers and foremen in project and so to get their ideas and make them feel that they are part of the action,
- to get management to back ourselves up, because total commitment by everyone is necessary for success,
- to be honest in answering questions from the workers,

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- to provide comprehensive maintenance training of sufficient personnel to cover all shifts and give them the tools necessary to do their jobs,
- to use our imagination and consider alternatives to the usual floor mounting of robots, or, not to simply imitate a man with a robot because there may be the better ways,
- to start with the simple applications (corollary of Murphy's law says "If you have 50%-50% chance of success, there is a 75% chance of failure".)

It is obvious that the success of first robot application in shipyard is dependent on the efforts made to apply the above considerations. Anything less than maximum dedication to all of the above colud result in some degree of failure.

2. THE ANALYTIC HIERARCHY PROCESS

Industrial processes today seems to consist of many complex nonlinear problems which feed one another. Every industrial plant can be described as a complex system of interacting factors. It is a network of factors whose causes and effects are not easily identified. Nearly all of us have been brought up to belive that clear headed logical thinking is our only sure way to face and solve complex problems. Our feelings and our judgments must be subjected to the rigorous test of deductive thinking. But experience suggests that deductive thinking is simply not natural, so we have to be trained, and for a long time, before we can do it well.

It is generally believed that because the industrial processes are so complicated, that to solve real problems in such a processes, we need to think in a complex way. In fact, we probably do not need a more complicated way of thinking. Most of us have difficulty examining even a few ideas at a·time. We need an approach to organize our problems in complex structures but which also allow us to think about them one or two at a time. In other words, we need a conceptually simple and decisionally robust approach, so that we can use it easily and that it can handle real systems complexities.

The Analytic Hierarchy Process (AHP) derived by Saaty | 6 | is such a problem-solving framework. It is a systematic procedure for representing the elements of any problem. It organizes the basic rationality by breaking down a problem into its smaller constituent parts and then calls for only simple pairwise comparison judgments to develop priorities in each hierarchy.

The Analytic Hierarchy Process does not insist on explanations. It provides a comprehensive framework to cope with the intuitive, the rational and the irrational in us all at the same time. It is a method we can use to integrate our perceptions and purposes into an overall synthesis. The Analytic Hierarchy Process does not require that judgments be consistent or even transitive. The degree of consistency of the judgments is revealed at the end of the process.

The Analytic Hierarchy Process consists of eight steps. Particular steps may be emphasized more in some situations than in others, and interaction is generally necessary:

1. Define the problem and determine what you want to know.
2. Structure the hierarchy from the top (the objectives from a general viewpoint) through the intermediate levels (criteria on which subsequent levels depend) to the lowest level (which usually is a list of the alternatives).
3. Construct a set of pairwise comparison matrices for each of the lower levels -one matrix for each element in the level immediately above. An element in the higher level is said to be a governing element for those in the lower level since it contributes to it or affects it. In a complete simple hierarchy, every element in the lower affects every element in the upper level. The elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgments. The pairwise comparisons are done in terms of which

element dominates another. These judgments are then expressed as integers (see Table I for judgment values). If element A dominates over element B, then the whole number integer is entered in row A, column B and the reciprocal (fraction) is entered in row B, column A. Of course, if element B dominates element A then the revers occurs. The whole number is then placed in the B, A position with the reciprocal automatically being assigned to the A, B position. If the elements being compared are equal, a one is assigned to both positions.

4. There are n(n-1)/2 judgments required to developed the set of matrices in step 3 (clearly, reciprocals are automatically assigned in each pairwise comparison).

5. Having made all the pairwise comparisons and entered the data, the consistency is determined using the eigenvalue: $Aw=\lambda_{max}$ w is determined. The consistency index then using the departure of λ_{max} from n compared with corresponding average values for random entries yielding the consistency ratio CR.

6. Steps 3), 4), and 5) are performed for all levels and clusters in the hierarchy.

7. Hierarchial composition is now used to weight **the** eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

8. The consistency of the entire hierarchy is found by multiplying each consistency index by the priority of the corresponding criterion and adding them together. The result is then divided by the same type of expression using the random consistency index corresponding to the dimensions of each matrix weighted by the priorities as before. Note first that the CR should be about 10 percent or less to be acceptable. If not, the quality of the judgments should be improved, perhaps by revising the manner in which questions are asked in making the pairwise comparisons. If this should fail to improve consistency, then it is likely that the problem should be more accurately structured; that is, grouping similar elements under more meaningful criteria. A return to step 2) would be required, although only the problematic parts of the hierarchy may need revision.

Table I. Scale of relative importance

Intensity of Relative Importance	Definition	Explantion
1	Equal importance	Two activities contribute equally
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong	Experience and judgment strongly favor one activity over another
7	Very strong importance	An **activity** is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	When compromise is needed

3. PRIORITY SETTING OF SURFACE PROTECTION WORKING PLACES AND OPERATIONS

The operations of surface protection in shipyards are very important, hard, danqerous and fatiquing jobs. For these reasons we chose surface protection operations for the first application of industrial robot in shipyard.

The problem was to decide which working places and operations in surface protection to chose for the first application of industrial robot. The first step is the decomposition of the problem as a hierarchy.

In the first level is the overall goal: "The right first application of industrial robot in shipyard." In the second level are seven factors of criteria which are to be evaluated in terms of the criteria of the second level |5| (Fig.1.).

Factors of criteria are: sociological factor, fluctuation (SOC); psyhological factor, motivation (PSY); technological factor (TCO); technical factor (TCI); workers safety factor (SAF); productivity factor (PRO); economical factor (ECO).

Alternative locations are: iron sheet preparation (loc.A); pre-equipping on supports (loc.B) whith two (2) microlocations; slide way (loc.C) whith six (6) microlocations; equipping shore (loc.D) with seven (7) microlocations.

After the inquiring of seventeen workers, five foreman and authors, the pairwise comparison matrix of factors of criteria occurs (Table II).

Table III shows four (of seven) matrices of the locations and their local priorities with respect to the factors of criteria.

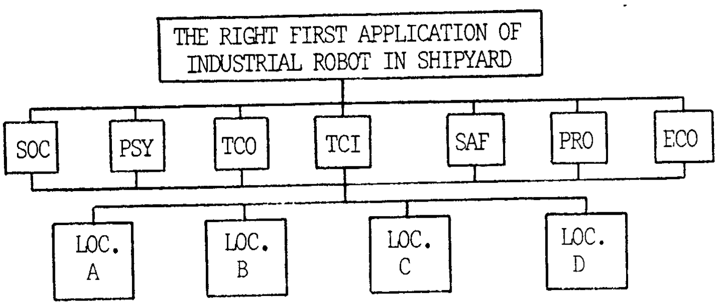

Fig.1. Decomposition of the problem into a hierarchy

Table II. Pairwise comparison matrix of factors of criteria

	SOC	PSY	TCO	TCI	SAF	PRO	ECO	PRIORITY VECTOR
SOC	1	1/2	1/5	1/5	1/8	1/6	1/3	0,027
PSY	2	1	1/3	1/5	1/4	1/3	1/2	0,049
TCO	5	3	1	2	1/4	1/3	4	0,140
TCI	5	5	1/2	1	1/4	1/2	2	0,116
SAF	8	4	4	4	1	5	7	0,422
PRO	6	3	3	2	1/5	1	3	0,185
ECO	3	2	1/4	1/2	1/7	1/3	1	0,060

CI = 0,099 CR = 0,075 $\lambda_{max} = 7,595$

Table III. Matrices of the locations for safety, productivity, technological and technical factors of criteria

SAFETY

	A	B	C	D	PRIORITY VECTOR
A	1	1/5	1/7	1/8	0,042
B	5	1	1/3	1/5	0,129
C	7	3	1	1/3	0,270
D	8	5	3	1	0,559

CI = 0,067 λ_{max} = 4,201
CR = 0,074

PRODUCTIVITY

	A	B	C	D	PRIORITY VECTOR
A	1	1/2	1/3	1/2	0,120
B	2	1	2	4	0,435
C	3	1/2	1	3	0,307
D	2	1/4	1/3	1	0,139

CI = 0,081 λ_{max} = 4,243
CR = 0,090

TECHNOLOGICAL

	A	B	C	D	PRIORITY VECTOR
A	1	1/2	1/3	1/2	0,120
B	2	1	2	3	0,412
C	3	1/2	1	3	0,317
D	2	1/3	1/3	1	0,150

CI = 0,072 λ_{max} = 4,215
CR = 0,079

TECHNICAL

	A	B	C	D	PRIORITY VECTOR
A	1	1/4	1/4	1/4	0,072
B	4	1	3	3	0,494
C	4	1/3	1	2	0,253
D	4	1/3	1/2	1	0,180

CI = 0,072 λ_{max} = 4,215
CR = 0,079

The next step is to apply the Principle of Composition of Priorities.

Because of extremely low global index of priority of location A this location is excluded from further investigation, so the revalorized vector of global priorities of location is:

$$\begin{vmatrix} B \\ C \\ D \end{vmatrix} = \begin{vmatrix} 0,2985 \\ 0,3120 \\ 0,3895 \end{vmatrix}$$

It is obvious that location D is on the first place, location C on the second, and location B on the third place of the rang-list of priorities, but the differences are not significant. On this stage it points out that the problem area is very complex and that the further steps has to be very careful and detailed.

At this point the goal is to derive the priority of observed microlocations. The new factors of criteria of this new hierarchy are: geometry of working place (shapes and dimensions) (GEO); approachability of working place (APP); safety of application of industrial robot (SAF) and productivity (PRO).

Our investigation leads towards the pairwise comparison matrix of these new factors of criteria. After that on each location the microlocations are defined (for instance, on location D the microlocations are: plating over sea level, deck, store places, tanks, hull blocks, peak tanks, super structure, engine room, etc.). At this stage it is important to point out the following statement: from economical, technical and other points of view, for every microlocation (or even for a few similar microlocations) we have to suggest the universal manipulator for all the surface protection operations (blasting, grinding, cleaning and painting).

All alternative microlocations are evaluated after pairwise comparison in terms of the defined criteria. The hierarchy sequence of microlocations in terms of the first right application of industrial robot in surface protection jobs (blasting, grinding, cleaning and painting) in shipyard is evaluated by weighting the priority vectors of microlocations with elements of the global priority vector of locations. (Fig.2., Table IV)

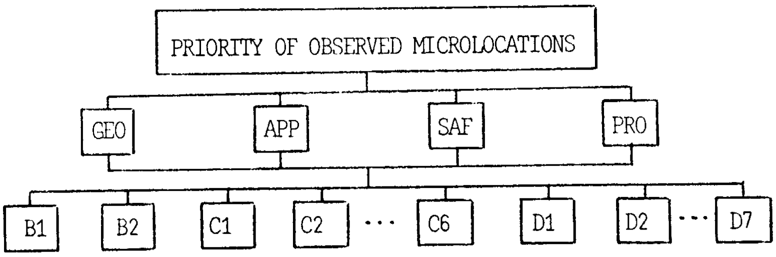

Fig.2. Decomposition of the problem into a hierarchy

Table IV. Pairwise comparison matrix for the new factors of criteria

	GEO	APP	SAF	PRO	PRIORITY VECTOR
GEO	1	1/3	3	3	0,250
APP	3	1	5	4	0,529
SAF	1/3	1/5	1	4	0,146
PRO	1/3	1/4	1/4	1	0,075

CI = 0,119

CR = 0,133

λ_{max} = 4,358

After applying the Principle of Composition of Priorities the resulting rang-list of priorities of observed microlocations is derived (Table V)

Table V. Rang-list of global priorities of observed microlocations

Rang	Sign	Microlocation	Global Priority index
1.	D1	Plating over sea level	0,1625
2.	C2	Plating under sea level	0,1416
3.	C1	Plating over sea level	0,1122
4.	D2	Deck	0,1085
5.	B2	Chimneys	0,0914
6.	D7	Super structure	0,0831
7.	D3	Store places	0,0777
8.	C3	Engine room	0,0488
9.	D6	Engine room	0,0358
10.	D4	Tanks	0,0327
11.	C4	Pump rooms	0,0308
12.	B1	Duble hull blocks	0.0215
13.	D5	Peak Tanks, wing tanks	0,0156
14.	C5	Duble hull blocks, peak and wing tanks	0,0153
15.	C6	Duble hull blocks for fuel and water	0,0097

4. PRIORITY SETTING OF MANIPULATOR STRUCTURES AND CONFIGURATIONS ON PRIORITY MICROLOCATIONS

Applying the method of the Analytic Hierarchy Process the rang-list of priorities of observed microlocations for the right first application of industrial robot on surface protection jobs in Shipyard Industry "Split" was derived. After introducing the results of these general investigations on two types of ships (crude oil tank ships and general cargo ships) in terms of appropriate working surfaces and productivity costs, we get appropriate vectors of global priorites of microlocations for these two types of ships.

After detailed analysis we decided to chose the priority structure and configuration of manipulator at following microlocations and/or group od microlocations:

1. Microlocations C1 (plating over sea level on location C), D1 (plating over sea level on location D) and D3 (store places),
2. Microlocation C2 (plating under sea level),
3. Microlocation D4 (store tanks),
4. Microlocation B1 (double hull blocks).

The priority manipulator's structure and configuration choice is a new complex problem and we decompose it on a new three level hierarchy. In the first level is the overall goal: "The right choice of manipulator's structure and configuration on particular microlocation". In the second level are five new factors of criteria and in the third level there are manipulators - alternatives (Fig. 3.). New factors of criteria are: possibility of installing (PI); manipulator's price (MP); control features (CF); working velocity (WV); energy consumption (EC).

Manipulators-alternatives are various structures and configurations of manipulators for particular microlocations.

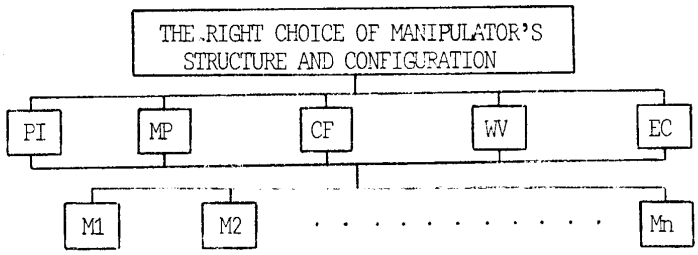

Fig. 3. Decomposition of the problem into a hierarchy

The pairwise comparison matrix of new factors of criteria is on Table VI.

Table VI. Pairwise comparison matrix of factors of criteria

	PI	MP	CF	WV	EC	PRIORITY VECTOR
PI	1	7	3	5	9	0,504
MP	1/7	1	1/4	1/5	2	0,055
CF	1/3	4	1	4	7	0,271
WV	1/5	5	1/4	1	4	0,135
EC	1/9	1/2	1/7	1/4	1	0,035

CI = 0,087 CR = 0,078 $\lambda_{max} = 5,348$

Using Analytic Hierarchy Process (pairwise comparisons and judgments, local priorities, principle of composition) we derived global vectors of priorities of manipulators-alternatives on particular microlocations and/or group of microlocations (Table VII). Basic design ideas of priority manipulators are on Fig.4.,5.,6. and 7.

Table VII. Rang-lists or priorities of manipulators on particular microlocations or group of microlocations

Group of microlocations C1, D1 (plating over sea level) and D3 (store places)			Microlocation C2 (plating under sea level)		
1. selfmoving manipulator	(SM)	0,491	1. Selfmoving manipulator	(SM)	0,476
2. manipulator on vehicle	(MV)	0,317	2. Manipulator on vehicle	(MV)	0,343
3. manipulator on rails	(MR)	0,192	3. Manipulator on rails	(MR)	0,181
Microlocation D4 (store tanks)			**Microlocation B1 (double hull blocks)**		
1. Fixed manipulator	(FM)	0,646	1. Fixed manipulator	(FM)	0,557
2. Manipulator on vehicle	(MV)	0,354	2. Manipulator on rails	(MF)	0,443

6. CONCLUDING REMARKS

The conception of industrial robot introduction in shipyard has been derived. The Analytic Hierarchy Process has been used as a complex problem-solving framework. The operations of surface protection have been analyzed. The numerical measures of priority of observed locations, microlocations and operations were derived. The priority structures and configurations of adequate manipulators for particular microlocations have been derived and their basic design ideas have been suggested. The workers, foremen and authors have been working together throughout the entire project and the results seem to be objective and real.

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REFERENCES:

1. Anon: Robots for Shipyards, common research study of MITI (Ministry of International Trade and Industry), JIRA (Japan Industrial Robot Association) and MOTO (Ministry of Transport), Japan, 1984.
2. Y.Fujita, H.Fujino, A.Ichikawa: The Conditions for Application of Arc Welding Robots in Shipbuilding, Computer applications in the automation of shipyard operation and ship design IV,Holland Publishing Co.,IFIP 1982.
3. R.J.Hewitt,J.G.Love: The Application of Robotic Welding Technology to Shipbuilding, Proceedings of 13 th I.S.I.R., Chicago, 1983.
4. G.C.Macri: Analysis of First UTD Installation Failures, Presented at the Robots II Conference, October 31.-November 3., 1977.
5. I.Mandić,D.Stipaničev,A.Krstulović,Ž.Domazet: Priority Setting of Industrial Robots Working Places and Operations in Shipyards, Proceedings of 7 th IASTED Int.Symp. Robotics and Automation 85. p.p. 94-97, June 24-26, 1985. Lugano, Switzerland
6. T.L.Saaty: Priority Setting in Complex Problems, IEEE Trans. on Engineering Management, Vol. EM-30, No.3, August 1983. pp. 140-155.

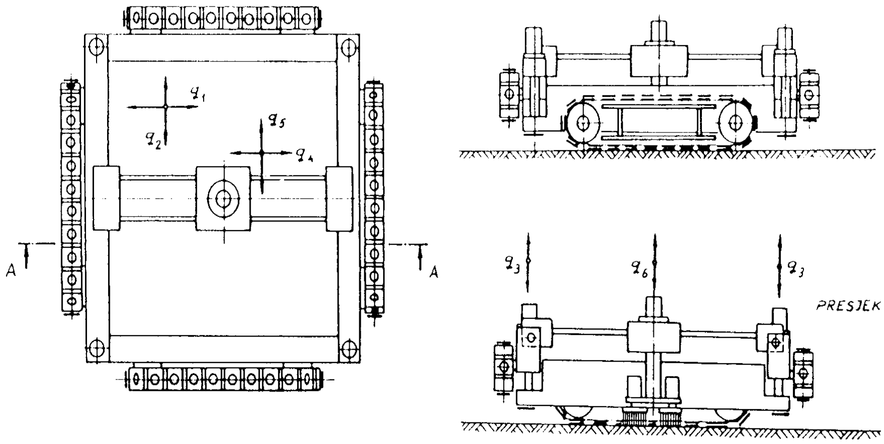

Fig. 4. Selfmoving caterpillar manipulator (SCM) for microlocations C1, D1, D3 and C2

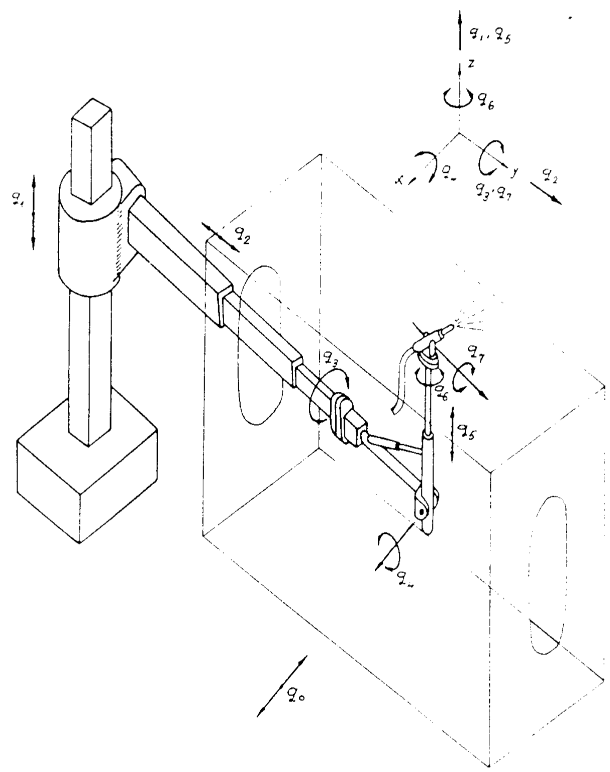

Fig. 5. One-hand fixed manipulator (F1M) for microlocation B1

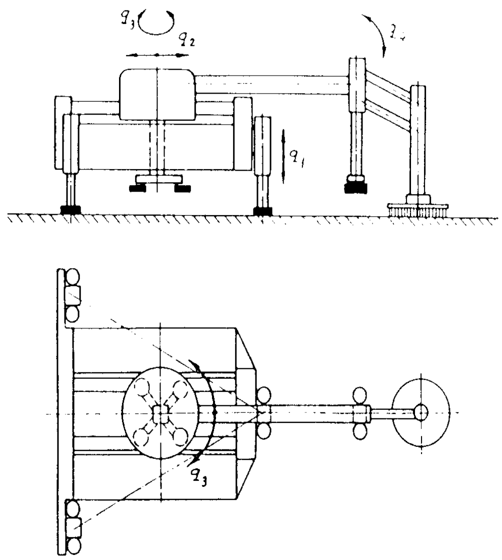

Fig. 6. Selfmoving legged manipulator (SLM) for microlocations C1, D1, D3 and C2

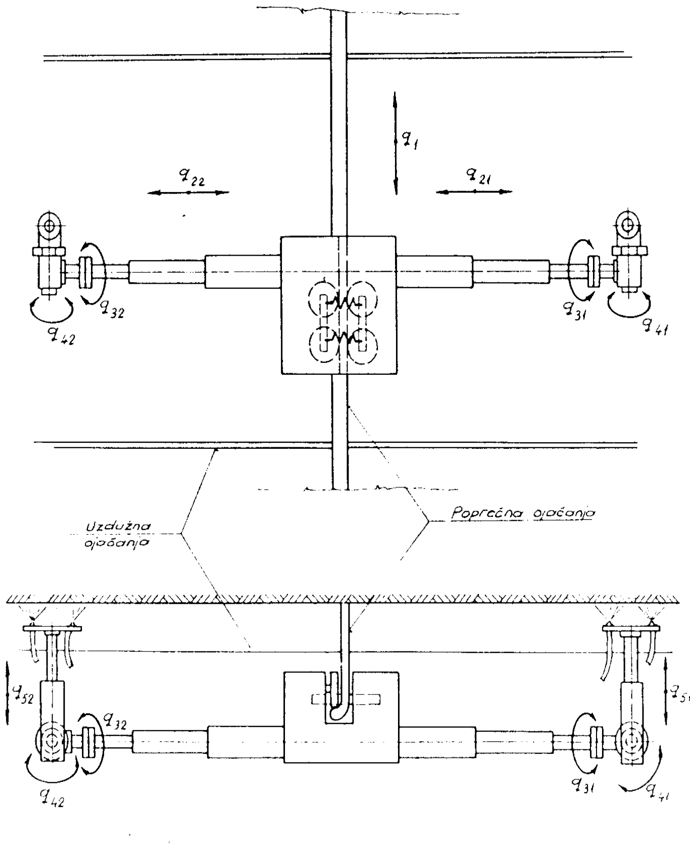

Fig. 7. Two-Hand "fixed" manipulator (F2M) for microlocation D4