Analyze of the Dynamic Behavior of Robots by Using the Proper Assisted Platform ROBO-PVAFM

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***Abstract*—The analyze of the dynamic behavior is the more important problem to solve in Robotics. By determined the best dynamic parameters like answer time, transitory time, short oscillation time, will be assured the movements without vibrations, without salts of the forces and movements vectors that amplifying the imprecision and stability of the robot's arm movements. It is more important that the variation of the velocities and acceleration to be minimum to determine also the minimum of the forces and moments.**

***Index Terms*—Assisted analyze, dynamic behavior, assisted platform.**

I. Introduction

The current research as well as the analyzed assisted platforms have focused on tracing the various characteristics of speeds, accelerations, forces and moments or on the assisted tracing of 3D trajectories without making a detailed analysis of the causes that lead to a behavior, from a dynamic point of view, very bad, without indicating the constructive functional parameters that predominantly influence the variation of forces and moments, determine vibrations of the end-effector. The analyzed software [6-15] confirmed that the current researches did not cover the entire field of analysis, i.e. the influence of the dimensions of the bodies on the variation of the kinetic moment was not analyzed, it was not analyzed how the parameters of the speed characteristics influence the variations of speed, acceleration, in finally Coriolis forces and moments. From the literature could remarks that many design methods begins with dimensioning its various links to meet performance specifications, most of them without assisted analyze them. One new concept so called "*manipulability*" was introduced by Yoshikawa [1] as measure the ability of robotic mechanisms in positioning and orienting end effecters. Other new kinematic parameters was introduced by Asada [2] so called "*inertia ellipsoid*" as a parameter to measure the capability to change the end effecter velocity. In [3], was introduced the concept of "*homogeneous space*" to design the concept of characteristic length. Other kinematic performance that affect the shape of the workspace is the so called "*stroke*" that mince the offset between maximum reach and minimum reach of the end effecter. Ma and Angeles [4] showed how could be optimizing the architecture of a manipulator under dynamic isotropy conditions and show one new forward methods which focus on the kineto- static optimization of manipulators [5]. The simulation of a robot system is the more important way to show what is happened when where changed the some robot's dimensions, velocities, the space 3D trajectory, the acceleration time, the variation of the kinetic moment. RoKiSim [6] is a free multi-platform educational software tool for 3D simulation of serial six-axis robots developed at the Control and Robotics Lab of the École de technologie supérieure, Montreal, Canada visualize by using the Denavit-Hartenberg parameters [7], all possible robot configurations and solutions of the inverse kinematics for a given position of the end-effector and orientations in any Euler angle conventions (such as FANUC Robotics, KUKA Robotics, Stäubli, and Adept Technology), as well as in unit quaternions (used by ABB Robotics). RobotStudio software employs, the real robot program what could change controller and the configuration file that are identical to the real one. Other simulation products like WorkspaceLt [8], Gazebo [9], Open Dynamics Engine [10], RoboticSimulation [11], SimRobot [12], RoboAnalyzer [13], NI-Robotics [14], RoboNaut [15], Bullet Physics [16], NVidia PhysX [17] or DART [18]. In other papers [19-28] authors show some characteristics and solve direct and inverse kinematics problem and also the direct and inverse dynamic problem, but without show the mathematical matrix model and without analyze how could be influenced the forces and moments variation by different velocity variations or to have the possibility to choose the parameters of the trapezoidal velocity characteristics to obtain the minimum variation of these forces and moments between some studied cases.

After were analyzed state of art in the field of Kinematics of robot, the papers [1-28] we can do the following remarks: (i) many of the researchers not used the mathematical matrix form in positions, velocities, accelerations, forces and moments; (ii) the kinematic behavior analyze not used the trapezoidal characteristics with the different origin of time for each movement and other characteristic parameters like: the acceleration and deceleration time, the constant value of velocity that in proposed software platform was calculated by using the space movement in each joints that will be established; (iii) the assisted kinematic analyze proposed by

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this paper have the possibility to change the different parameters of the velocity characteristics: constant value of velocity, the movement time of cycle; (iv) with this new software platform will be possible to study how was influenced the velocity variation when were changed some of the velocity characteristic, with the final goal to obtain one minimum of end-effecter velocity variation; (v) in the paper was shown one way to optimize the variation of all kinematic and dynamic parameters and choose the best solution of the movement type: simultaneously, successive and complex, using the proper pounder theory.

II. DESCRIPTION OF THE PROPER PLATFORM

A. Description of the front panel of the platform

We can see on the front panel of the proper platform ROBO-PVAFM the following modules for each DOF: one cluster for the dimensions, material and the filling coefficient for each body, one cluster for the velocity's parameters, one matrix with two dimensions for position vector of each robot's joints, cluster with information about the type of the movement, direction of the movement, the home position, the position of the couple regarding the principle of action and reaction in the forces equilibrium, in each joints, the column matrices for the G and Z matrices that define the position in the space of each robot's joints, the robot image with the Cartesian systems and associated graph of the robot structure.

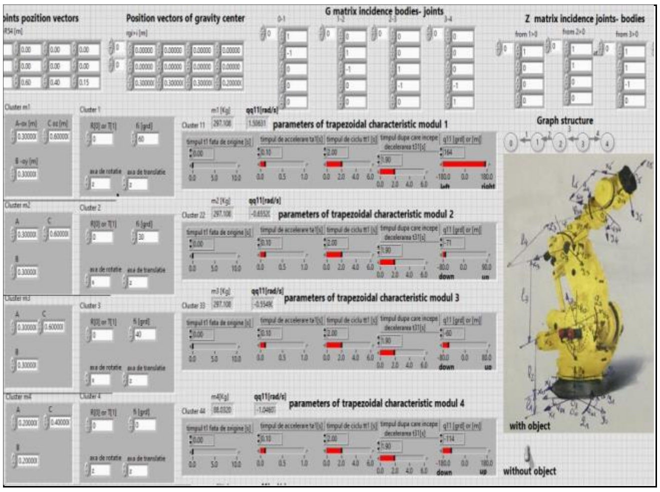


Fig.1. Front panel of the proper platform ROBO-PVAFM

B. Description of the obtained results

The results consist in obtain the positions, velocities, accelerations, forces and moments 2D and 3D characteristics variation vs. time. The results contents also the variation of the angle between these vectors vs. the base to determine the maximal variations of them. After were analyzed these results, fig.2, we can do the following remarks: (i) to see the 3D characteristic of the end-effecter position we can avoid the singular points and could establishing 3D working space; (ii) with 3D variations of the angular and linear velocities and accelerations we can determine the minimum variations of them; (iii) we can do the assisted analyze of the 3D variations of forces and moments by changing some constructive and functional parameters; (iv) by determining the number of forces and moments oscillation in the space we can establishing the forced vibrations of the robot.

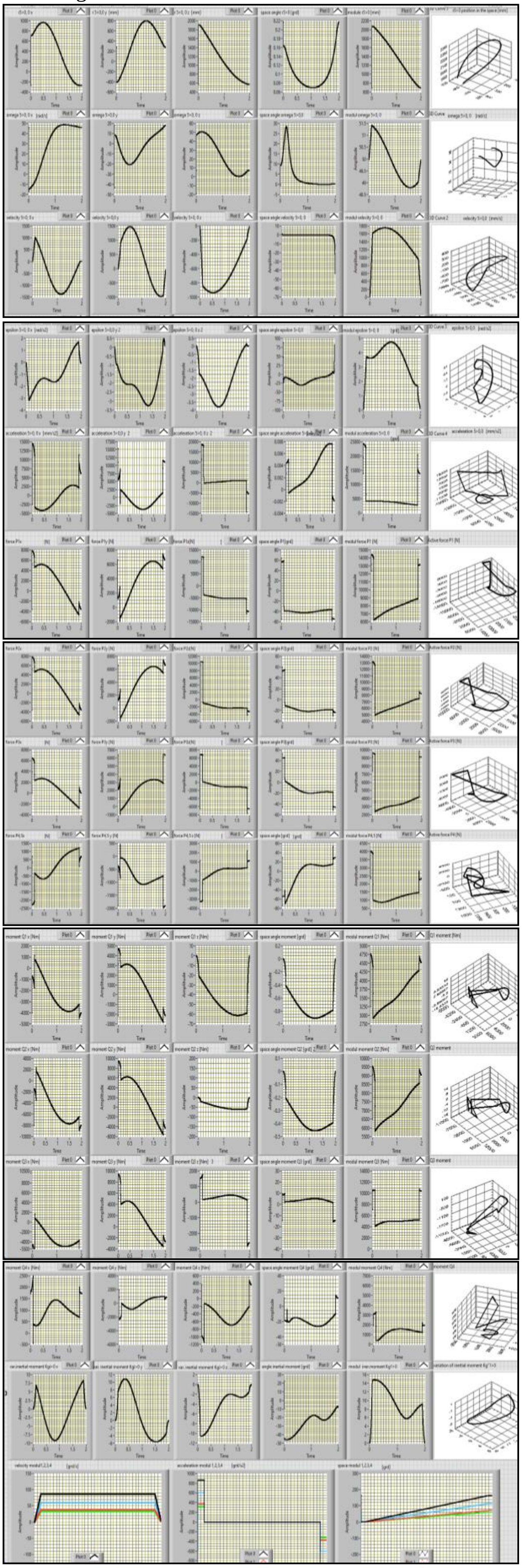


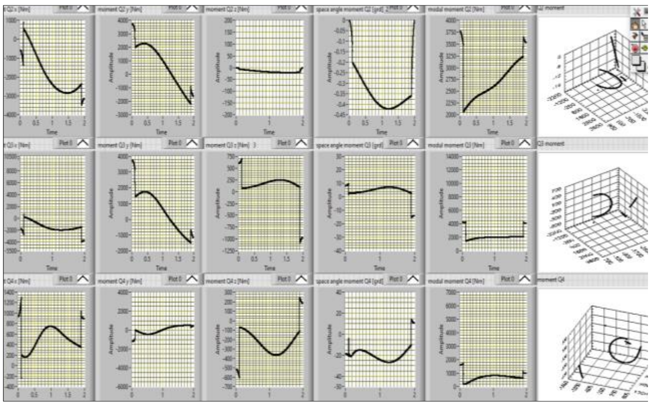
Fig.2. Some results of the used platform ROBO-PVAFM for the assisted analyze

C. *Advantages to use this platform*

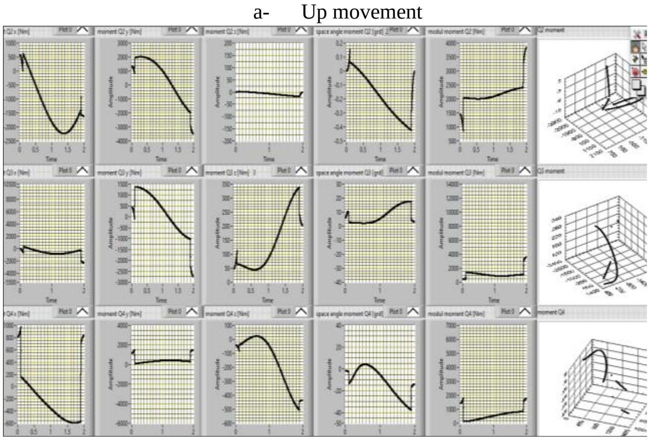
After were compared the proper proposed ROBO-PVAFM software platform to other similar platforms, we can do the following remarks: (i) this platform cover the possibility to analyze the variation of positions (P), velocities (V), accelerations (A), forces (F) and moments (M) in different conditions movements: successive, simultaneously or combination of them; (ii) the platform, by using the matrices of the incidence body-joints G and matrix of the incidence joints- bodies Z, cover the analyze of the joints position to the dynamic behavior; (iii) influence of presence or absence of the manipulated object in end- effecter; (iv) the influence of the change of the body's material and dimensions to the dynamic behavior was analyzed; (v) by using the cluster for each trapezoidal characteristics with the velocities parameters is possible to analysis haw influence each of them the dynamic behavior; (vi) the platform offers the possibility to see haw will be influenced each dynamic parameters by the constructive and functional parameters; (vii) the platform could be used to perform the inertia tensor of each robot's module. The platform cover the assisted analyze of the robots Arm, Scale, Cartesian, Portal and Gun robots. In the future, this platform will be designed for the analyze of multi robots application and for the animation of them.

III. SOME CHARACTERISTICS OF MOMENTS

The moments characteristics were shown for different change of the constructive- functional parameters like: velocities, length of some bodies, position of some joints, the movements in up or down direction. Some of these characteristics are shown in figs.3 and 4.

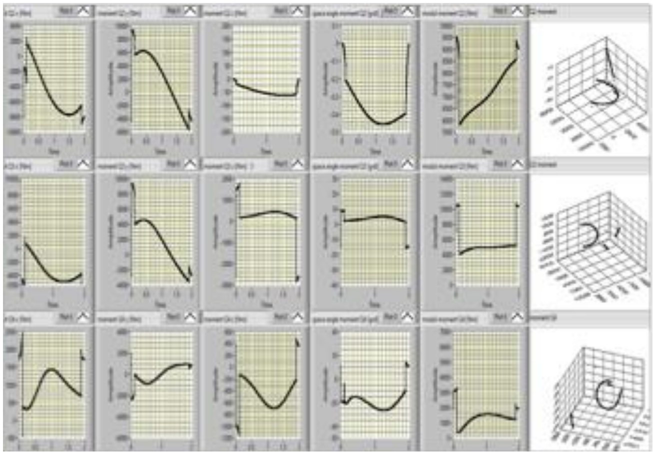


a- Up movement

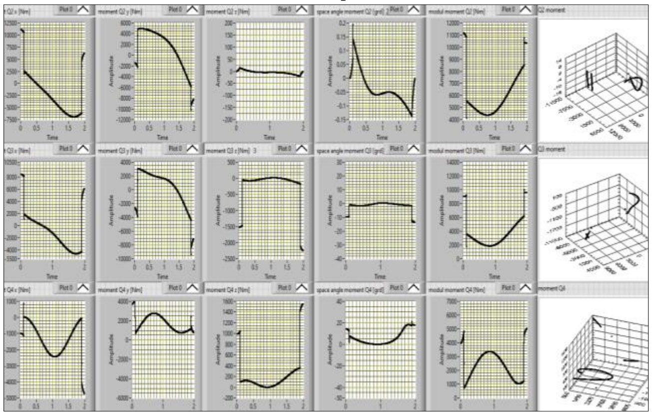


b- Down movement

Fig.3. The variation of moments in all joints of the Arm type robot with bodies from aluminum and when the length of the bodies is 0.6m, in the simultaneously movements 0-0-0-0 in up/down direction

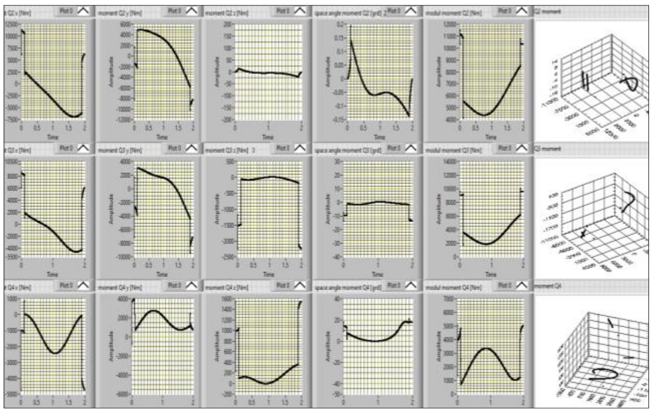


a- Up movement

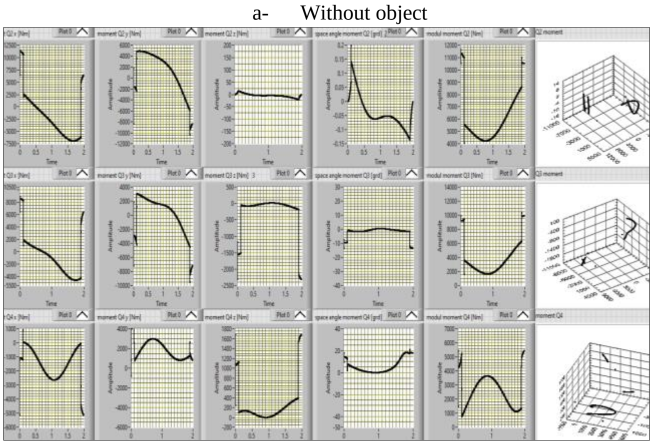


b- Down movement

Fig.4. The variation of moments in all joints of the Arm type robot with bodies from steel and when the length of the bodies is 0.6m, in the simultaneously movements 0-0-0-0 in up and down direction.



a- Without object



b- With object

Fig.5. The variation of moments in all joints of the Arm type robot with bodies from steel and when the length of the bodies is 0.6m, in the simultaneously movements 0-0-0-0, with/without object.

IV. Assisted Analyze

In order to analyze the way in which various constructive-functional parameters influence the dynamic behavior, the method of tracing the characteristics of the variations of active moment in the joints and comparing the obtained characteristics was used. The front panel of the software platform, fig.1 includes both the input data and the obtained results. The multi-object optimization function is: (1)

$$MOF(t_i, tt_i, t_{ai}, t_{di}, l_i, \varphi_i) =$$

$$\min(\text{range}M_{1x,y,z}) \cap \min(\text{range}|M|_1 \cap \min(\text{range} < M_1) \cap \min(\text{range}M_{2x,y,z} \cap \min(\text{range}|M|_2$$
$$\min(\text{range} < M_2) \cap \min(\text{range}M_{3x,y,z} \cap \min(\text{range}|M|_3) \cap \min(\text{range} < M_3) \cap$$
$$\min(\text{range}M_{4x,y,z}) \cap \min(\text{range}|M|_4) \cap \min(\text{range} < M_4)$$

and the relation used the weight theory [29]:

$$\boldsymbol{MOF} = \max\left(\sum_1^{20} p_i \frac{M_{i,x,y,z,<,min}}{M_{i,x,y,z,<,crt}}\right)_{\text{cases}} \quad (2)$$

These characteristics will be the basis for the assisted analysis of the various influences of the constructive-functional parameters on the variation of the active moments in the joints. The results of analyze of moment were changed the type of movements is shown in table I and figs.3-5.

TABLE I- THE WEIGHT THEORY APPLIED TO THE MOMENTS

Movement	100	100	100	100	100	100	
0-0-0-0	38,8235294	46,6666667	51,5789474	80	65,7894737	52,6315789	335,490196
0-2-4-6	100	93,3333333	84,4827586	88,8888889	86,2068966	47,6190476	500,530925
0-3-6-9	94,2857143	100	89,0909091	100	83,3333333	46,5116279	**513,221585**
0-0-2-2	82,5	87,5	100	88,8888889	100	52,6315789	511,520468
0-2-0-2	50,7692308	48,2758621	65,3333333	94,1176471	65,7894737	48,7804878	373,066035
2-2-0-0	41,25	70	61,25	88,8888889	45,4545455	41,6666667	348,510101
2-0-2-0	67,3469388	100	81,6666667	80	62,5	100	491,513605
0-0.1-0.2-0.3	63,4615385	73,6842105	75,3846154	88,8888889	83,3333333	44,4444444	429,197031

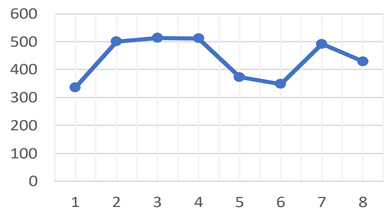
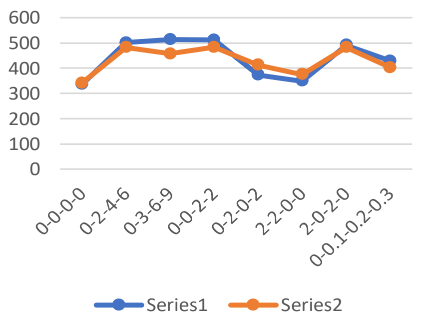


Fig.6. The moments variation vs. type of movements

A. *Influences of the robot's length to the dynamic behavior*

		l2=1.0m
0-0-0-0	335,490196	341,547831
0-2-4-6	500,530925	482,297832
0-3-6-9	**513,221585**	456,629318
0-0-2-2	511,520468	**483,240793**
0-2-0-2	373,066035	412,49269
2-2-0-0	348,510101	374,77393
2-0-2-0	491,513605	482,72449
0-0.1-0.2-0.3	429,197031	402,432377



Series 1- without change the lengths; series 2- where was changed l_2;
Fig.7. The moments variation when was changed the l_2 length.

0-0-0-0	335,490196	341,547831	405,845865
0-2-4-6	500,530925	482,297832	474,68254
0-3-6-9	**513,221585**	456,629318	470,43956
0-0-2-2	511,520468	**483,240793**	**507,019445**
0-2-0-2	373,066035	412,49269	465,480582
2-2-0-0	348,510101	374,77393	439,267399
2-0-2-0	491,513605	482,72449	458,237179
0-0.1-0.2-0.3	429,197031	402,432377	392,218323

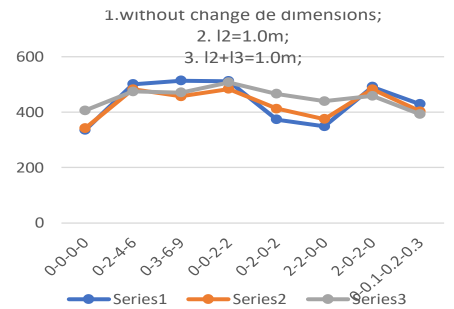
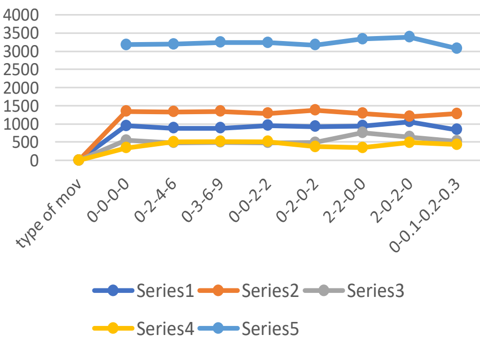


Fig.8. The moments variation without any change and when were changed the l_2 , respectively l_2 and l_3 length

B. *Influences of the robot's velocities, accelerations, forces and moments to the dynamic behavior*

TABLE II- THE WEIGHT THEORY APPLIED TO THE VELOCITIES, ACCELERATIONS, FORCES AND MOMENTS VARIATION VS. THE TYPE OF MOVEMENTS

type of mov	velocities	acceleration	forces	moments	
0-0-0-0	951,878	1347,87	543,74	335,490196	3.178,978
0-2-4-6	884,200	1.328	480,78	500,530925	3.193,361
0-3-6-9	886,285	1344,83	498,12	513,221585	3.242,457
0-0-2-2	954,656	1288	480,65	511,520468	3.234,826
0-2-0-2	931,021	**1376,56**	491,57	373,066035	3.172,217
2-2-0-0	938,436	1288,16	**757,57**	348,510101	3.332,676
2-0-2-0	**1.055,057**	1201,55	637,73	**491,513605**	**3.385,851**
0-0.1-0.2-0.3	843,805	1279,16	524,25	429,197031	3.076,412



series1- velocities; series 2- accelerations; series 3- forces; series 4- moments; series 5- sum of them
Fig.9. The variation of velocities, accelerations, forces, moments and sum of them versus the type of movements

After were comparative analyzed the figs.6-9 we can do the following remarks: (i) the movement 0-0-2-2 is more efficiently from dynamic behavior point of view, when were changed the lengths of bodies or without these change; (ii) the sum of all influences variation of velocities, accelerations, forces and moments determine the best solution of movement to be 2-0-2-0; (iii) variation of the velocities determine the best solution of the movement to be 2-0-2-0; (iv) variation of the accelerations determine the best solution of movement to be 0-2-0-2; (v) variation of the forces determine the best solution of movement to be 2-2-0-0; (vi) variation of the moments determine the best solution of the movement to be 2-0-2-0; (vii) in the sum of influences the more important is the variation of velocities and moments, have the same influence to choose the best solution of the movement 2-0-2-0, that mince the first and thread movement of joints is both successive after the second and four joints; (viii) the variation of the moments determine the best solution of movement to be 0-3-6-9, the successive movements in all joints with one second of break, but the increasing the length l_2 of the second robot body and also l_2 and l_3 , determine the best movement to be 0-0-2-2.

C. Influences of the materials and other dimensions to the dynamic behavior

	alumin.A,B>0.4	cast iron A,B>0.4	Sum
0-0-0-0	336,7521368	265,0877193	601,83986
0-2-4-6	247,6960784	277,421638	525,11772
0-3-6-9	247,6960784	275,410628	523,10671
0-0-2-2	265,3735632	311,6666667	577,04023
0-2-0-2	287,178105	309,2577031	596,43581
2-2-0-0	259,8978495	241,4957983	501,39365
2-0-2-0	338,7055567	333,3333333	672,03889
0-0.1-0.2-0.3	268,4461153	320,3508772	588,79699

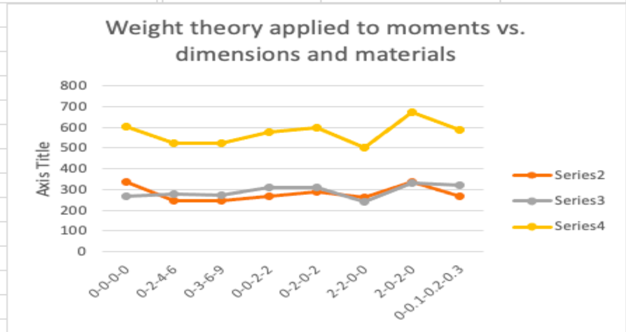


Fig.10.The results after was applied the weight theory to the moments variations vs. all base dimensions of the robot's bodies.

	steel	alumin.	cast iron	sum
0-0-0-0	220,15233	225,72537	354,16667	1020,1967
0-2-4-6	275,95238	290,12987	234,8062	1076,8408
0-3-6-9	314,28571	300,5848	224,90385	1154,0601
0-0-2-2	293,12997	333,33333	255,80294	1175,3962
0-2-0-2	270,26132	295,12987	232,98327	1068,6358
2-2-0-0	283,09091	226,34921	283,21429	1075,7453
2-0-2-0	296,91769	298,91534	244,26332	1137,014
0-0.1-0.2-0.3	272,39737	300,89717	209,73758	1055,4295

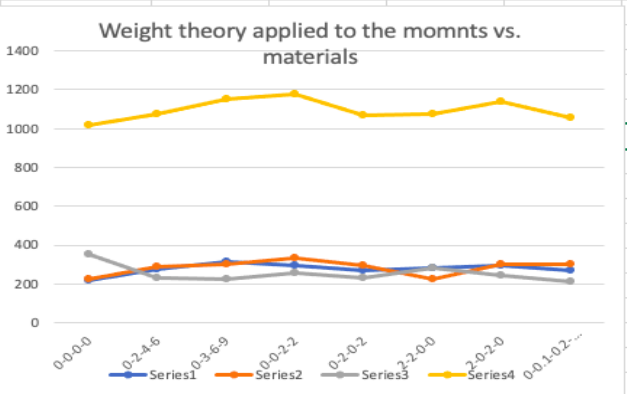


Fig.11. The results after was applied the weight theory to the moments variation vs. all materials of the robot's bodies.

After was analyzed the simulation results obtained by using the proper platform ROBO-PVAFM we can do the following remarks: (i) the best solution of the movements when were changed the base dimensions of all robot's bodies is the successive movements 2-0-2-0 two by two joints; (ii) for the steel material of all bodies the best solution is the successive movements with 1 second break between them, 0-3-6-9; (iii) for the aluminum materials of all bodies the best solution is successive and simultaneously movements two by two 2-0-2-0; (iv) for the cast iron the best solution is the simultaneously movement 0-0-0-0; (v) the optimal solution from the point of view of dynamic behavior and which does not depend on the material of the structure is 0-0-2-2.

*D. Influences of the position bodies-joints and joints-bodies, **G** and **Z** matrices of the joints to the dynamic behavior*

TABLE III. MIN-MAX VARIATION OF MOMENTS IN STUDIED CASES

Moment	x	y	z	<	modul
Simultaneously movement, joint position 2 and 3 were changed					
Q3	6000	14000	2250	20	8000
Q4	6000	8000	3000	40	3000
Simultaneously movement, joints in initial condition					
Q3	6000	15000	4500	35	4000
Q4	5500	4000	2250	40	3000
Successive movement, joints in initial condition					
Q3	5000	10000	3200	30	6900
Q4	4000	3000	1600	40	2500
Successive movement after 0.1s, joints in initial conditions					
Q3	4000	15000	4500	35	7000
Q4	5000	4000	2050	40	2500
Successive movement and simultaneously movement after 1.9s, joints in initial conditions					
Q3	5000	11000	3300	35	6000
Q4	4000	3000	1600	40	2500
Successive movement with 1s break, joints in initial conditions					
Q3	6500	10500	3300	30	6000
Q4	4000	3000	1600	40	2500

In the table III was shown the synthetic results concerning the maximum variation of the moments components by ox, oy, oz axes, variation of the moments module vectors and angles with the base plane of robot. With the blue color is the minimum variation of the Q_3 moment and with yellow the minimum variation of the Q_4 moment. After were analyzed all simulation results, we can do the following remarks: (i) the best solution with the minimum variation of the moment in the end-effector joint Q_4 will be the successive movement with one second break between them, 0-3-6-9; (ii) the best solution for the minimum variation of the moment in the joint three Q_3 will be the simultaneously movement,0-0-0-0 and after was changed the position the joints 2 and 3; this changed position change the sign in the **G** and **Z** matrices, body-joint and joint-body; (iii) the best solutions for the minimum variation of the moments vectors module in joint 3, Q_3 and in joint 4, Q_4 are the simultaneously movement 0-0-0-0, and respectively successive movements 0-2-4-6; (iv) the all successive movement 0-2-4-6 determine increasing the proper frequency of the end-effecter by induced the acceleration oscillations; (v) between the analyzed cases of simultaneously movement 0-0-0-0 with joint 2 and 3 in a new body-joint position and in the initial positions, the best solution for Q_3 is the case with joint 2 and 3 in new body-joint position, and for Q_4 is the case without any changes of joints 2 and 3.

V. CONCLUSION

The design of the proper new platform for assisted analyze of the dynamic behavior of industrial robots open the way to optimize the performances in Robotics. The assisted analyze and the results shown in the paper could be a great opportunity for the researchers in this field. Without using assisted research will be not possible to solve the difficult problem of the optimization in Robotics to touch the extreme precision of the end-effector in the space, without vibration, collisions and the minimum variation of the forces and moments.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The contribution of each author are: Olaru Adrian design the Robotics platform ROBO-PVAFM in LabVIEW software, the sub*VI*-s and written some part of the paper; Olaru Serban contributed at some LabVIEW sub*VI*-s, check the English language and written some part of the paper; Mihaela Ciorei contributed at the software algorithm and mathematical model of the kinematics modelling, check the English grammar and written some part of the paper; Mihai Niculae contributed with experimental research with the proper arm type robot from his private company, Leuval, Canada. All authors had approved the final version of the paper.