STUDIES ON THE EFFECT OF VIBRATION OF ROBOT LINKS ON THE END POINT TRAJECTORY PATH USING CAD

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ABSTRACT

In this paper, the dynamics of a two-link flexible manipulator has been studied by the computer aided design (CAD) procedure. First, a database file was created for the end point trajectory, velocity and acceleration, and the payload. Then, a database file was constructed to define the geometry and material properties of the manipulator, and the external forces and torques. A general-purpose dynamic analysis computer program is used to find the angular positions, velocities, and accelerations of the links, and the joint forces, the necessary external torques, and the distributed inertial forces. The rigid body dynamics has been used in this program. The time varying (periodic) forces, torques and distributed inertial forces acting on the links are used as the input information for an available finite element analysis (FEA) program (ANSYS 5.0) to study the vibration of the inks. The output data from the FE program is used to analyze the effect of flexibility on the end point trajectories.

Keywords: vibration, trajectory path, computer aided dynamic analysis

1. INTRODUCTION

Flexibility effects increase as the weight of the robot manipulators decrease. It is desired to design lighter robots carrying out heavier payloads at higher speeds. Thus, the design of flexible link manipulators is a subject of intensive research. Designers of such manipulators need information about the dynamic response of the systems. Control actions can modulate the vibration effect of flexibility. There are many research works published on the dynamics and control of flexible manipulators [1-8].

In this study, a two-link flexible manipulator is considered. The dynamics of the manipulator is studied by the computer aided design (CAD) procedure. First, a database file is created for the end point trajectory, velocity and acceleration, and the payload. Then, a database file is constructed to define the geometry and material properties of the manipulator, and the external forces and torques. A general-purpose dynamic analysis computer program is used to find the angular positions, velocities, and accelerations of the links, and the joint forces, the necessary external torques, and the distributed inertial forces. The rigid body dynamics is used in this program. The time varying (periodic) forces, torques and distributed inertial forces acting on the links are used as the input information for an available finite element analysis (FEA) program (ANSYS 5.0) to study the vibration of the inks [9]. The output data from the FE program is used to analyze the effect of flexibility on the end point trajectories.

2. COMPUTER AIDED DESIGN (CAD)

The sketch of the manipulator is shown in Fig.1. The element numbers for the links are 2 and 3, respectively.

θ_i is the angular position of the i-th element, and Ti is the external torque acting on the ith element. $\mathbf{R}_B$ is the position vector of the end point, and $\mathbf{F}_B$ is the payload. l_i is the length of the link i; thus, l_2=OA and l_3=AB. m_i is the mass and I_i is the moment of inertia of the element i.
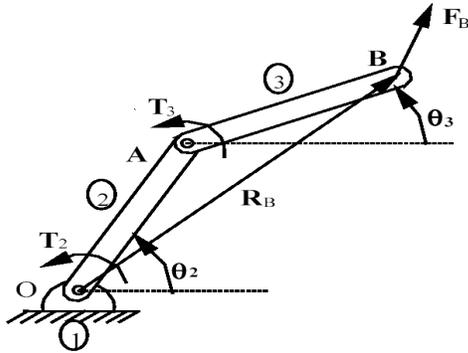

Fig.1 The manipulator

First, the input file is created to define the position, velocity, and acceleration of the end point, and the payload. The structure of the file, which is named as KESAV.INP is given below.

File-1: KESAV.INP
32, 4
1, T = 0
3, 0.496, 0, -394.7843
3, 0.159, 6.2832, 0
1, 0
1, -50
2, T = 0.003125
...
...

In the first line, the numbers 32 and 4 in the first line indicate that the calculations are done for 32 steps, and 4 sets of inputs exist. In the second line, 1 indicates the step number, and T = 0 gives the value of the time for this step. The third-to-sixth lines give the kinematic and kinetic input values for this step. The manipulator consists of 2 kinematic inputs (x- and y-coordinates of the end point), and 2 kinetic (force/torque) inputs (x- and y-components of the payload). The lines starting with 3 indicate kinematic inputs (position, velocity, and acceleration), and the lines starting with 1 indicate force/torque inputs. For the first step, the x-coordinate of the end point is 0.496 m, the velocity and acceleration in the x-direction are 0 m/s and -394.7843 m/s^2, respectively. The y-coordinate is 0.059 m, the velocity and acceleration in the y-direction is 6.2832 m/s and 0 m/s^2. The x- and y-components of the payload are 0 and -50 N, respectively, for the first step.

The value of time for the second step is 0.003125 s. The varying values of the kinematic and kinetic inputs follow in the same format as in the first step. After

preparing Input file, the file defining the manipulator system (REDDY.SYS) is created below.

File-2: REDDY.SYS
KESAV.INP, KESAV.OUT
`--------------------------------`
3 ELEMENTS
EL. 1, FRAME
EL. 2, LINK, 0.3, 0.15, 1.5, 0.01125
EL. 3, LINK, 0.4, 0.20, 2.0, 0.02667
`------------------------------------------`
0 CD VALUES
`------------------`
0 CA VALUES
`------------------`
2 KINEMATIC INPUTS
RBX
RBY
`------------`
1 VECTOR POLIGON
3 VECTORS
+, P, LL2, TH2
+, P, LL3, TH3
-, C, RBX, RBY
`------------------`
NITER1, NITER2/ XB ( ), XH ( )
5, 20
1.047, 0.001
5.75, 0.001
`------------`
POSITIONS OF CENTER OF MASSES
EL. 2, 1 VECTOR
+, P, LG2, TH2
EL. 3, 2 VECTORS
+, P, LL2, TH2
+, P, LG3, TH3
'----------------------
2 JOINTS
1, 2, RJ, 0, 0
2, 3, RJ, LL2, 0
'----------------------
2 EXTERNAL TORQUES
EL. 2, T2, 0
EL. 3, T3, 0
'----------------------
2 EXTERNAL FORCES
EL. 3, FBX, 0, LL3
EL. 3, FBY, 1.57, LL3
'----------------------
2 FORCE/ TORQUE INPUTS
FBX,FBY

The information KESAV.INP in the first line indicates the input file name above, and KESAV.OUT is the output file name where the results of the dynamic analysis program are stored. There are three elements in the system. Element-1 is always the frame. Elements -2 and -3 are the links as numbered in Fig. 1. In the file

REDDY.SYS, the length, the distance of the center of mass from the link origin, the mass, and the moment of inertia are given as 0.3m, 0.15m, 1.5kg, and 0.01125kg-m^2 for the element-2 (Link 2), respectively. The values for the link 3 are given in the similar format.

There are no constant distances (CD values) and constant angles (CA values) in the system. Two kinematic inputs: RBX and RBY, that correspond to the x- and y- coordinates of the end point (X_B and Y_B, respectively) are defined. From Fig.1, the following equation can be written:

$$R_A + R_{BA} - R_B = 0 \qquad (1)$$

where, R_A is the position vector of A with respect to O, R_{BA} is the position vector of B with respect to A, and R_B is the position vector of B with respect to O. Equation (1) can be written with complex numbers as:

$$l_2 e^{i\theta_2} + l_3 e^{i\theta_3} - (X_B + iY_B) = 0 \qquad (2)$$

Equation (2) is defined in File REDDY.SYS, after the line written as "1 VECTOR POLYGON". In the following lines, P indicates polar coordinates and C indicates Cartesian coordinates. For example, LL2 corresponds to l_2 (the length of the link 2) and TH3 corresponds to θ_3 (the angular position of the link 3). The real and imaginary parts of Equation (2) give two equations to solve θ_2 and θ_3.   The equations are nonlinear and can be solved by the Newton- Raphson method [6]. The minimum and maximum number of iteration numbers are defined as 5 and 20. The initial guesses for θ_2 and θ_3 are 1.047 and 5.75 radians, respectively, and the acceptable error values are 0.001 rad. The derivative of Equation (2) with respect to time is called the velocity equation and it is used to solve $\omega_2 = d\theta_2/dt$ and $\omega_3 = d\theta_3/dt$. The second derivative of Equation (2) with respect to time is called the acceleration equation and it is used to solve $\alpha_2 = d\omega_2/dt$ and $\alpha_3 = d\omega_3 / dt$. The velocity equation is linearly dependent on ω_2 and ω_3, and the acceleration equation is linearly dependent on α_2 and α_3. The position vectors of the center of masses are defined in the similar way as for the Equation (2). Here, for example, LG3 is the distance of the center of mass of the link-3 from its origin.

There are 2 joints in the system under study, which are defined in File 2. For example, the elements 2 and 3 are joined by a revolute joint (RJ), and the location of the joint in Link 2 is at the distance l_2 (LL2) from its origin, and in the link 3 is at its origin. There are 2   external orques. The variables T_2 and T_3 correspond to the torques acting on the elements 2 and 3, respectively. 1 external force (the payload) exists, but it is defined by 2 external forces in File 2. FBX is the x component, and FBY is the y component of the payload. It is acting on the link 3 at the distance l_3 (LL3). The direction angles of these components with respect to the x-axis are 0 and 1.57 radians, respectively.   The force/torque inputs are also indicated in File 2.

A general-purpose computer program is used to find the time-varying positions, velocities, and accelerations, and the external torques and the joint forces from the information given in Files 1 and 2. It can be used for simple mechanical systems in planar motion. The output file of the program gives the values of the angular positions, angular velocities, angular accelerations, acceleration vector components of the center of masses, external torques, and the longitudinal and vertical components of the joint forces for each time considered in the steps. The program uses equations of motions applied to the free body diagrams of the elements. The resulting equations are linearly dependent on the unknown forces and torques.

For each link, the geometry and material information, the external torque and joint forces acting on the link, and the distributed inertia forces are defined to the finite element   (FE) program (ANSYS 5.0) using its procedures [10 - 16]. The FE program gives the time varying displacements, velocities, accelerations, and strains at the nodes assigned. The required trajectory of the end point is called the rigid body (RB) trajectory. The displacement of the end point calculated by the FE program is added to the RB-trajectory to obtain the flexible body (FB) trajectory.

3. RESULTS AND DISCUSSIONS
 For obtaining the following results, it is assumed that the links are homogeneous and have constant cross sectional areas. The properties of the material of the links are assumed to be as E = 200 x 10^9 N/m^2, ρ = 7800 kg/m^3, ν = 0.35; where E is the elasticity modulus, ρ is the density, and ν is the Poisson's ratio. 8 nodes are assigned in the FE program. The end point trajectory is assumed to be a circular path for Fig. 2 and 3, and a linear path for Fig. 4.

The motion is taken as periodic. 32 points are considered in the period. The cycle speed is 600 cycles per minute, and $l_2 = 0.3$ m, $l_3 = 0.4$ m, unless it is stated. The displacement amounts due to the vibration are multiplied by 100 and added to the RB-trajectory in the figures in order to observe the effect of vibration clearly. For the circular trajectory, x_B = 0. 396 + 0.1cos(2π nt/60), and y_B = 0.059 +0.1sin(2 πnt/60) meters. n is the value of cycles per minute (cpm) and t is the time.

The payload is taken as perpendicular to the trajectory, with a constant magnitude of 50 N. The force is assumed to be in the direction giving a clockwise moment with respect to the center of the circular trajectory. The RB and FB- trajectories are shown in Fig.2 for different cross sectional areas (A). The deviations defined as the absolute values of the differences between RB and FB-trajectories in the radial direction, are studied in Fig. 3 for different cases. 32 sample points are considered.
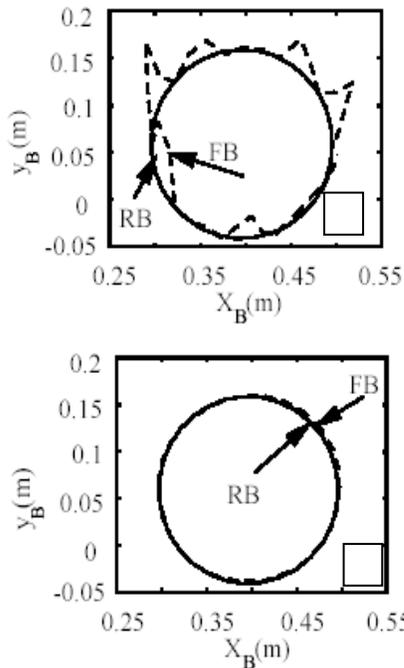

Fig.2 RB and FB- trajectories for a) A = 500 mm^2 and b) A= 1050 mm^2

As observed from Fig.3, the deviations increase as the cross sectional areas decrease, the l_3/l_2 ratio increase, or the speed of the cycle of the motion increase. These results are expected, because decreasing cross-sectional areas mean increasing flexibility and thus larger deflections. Increasing speeds results in higher forces and thus larger deflections.

Similar results are obtained for different trajectories. The end point trajectory is taken as a line in the vertical direction (y-direction) for the results shown in Fig. 4, where x_B = 0.412 m, and y_B = 0.21 - 0.1cos (2πnt/60) m. A force (payload) with a magnitude of 50 N in the negative direction is taken while the end point is moving upwards, and the force is zero while the motion is downward. The deviations from the RB- trajectory is defined here as the absolute values of the differences

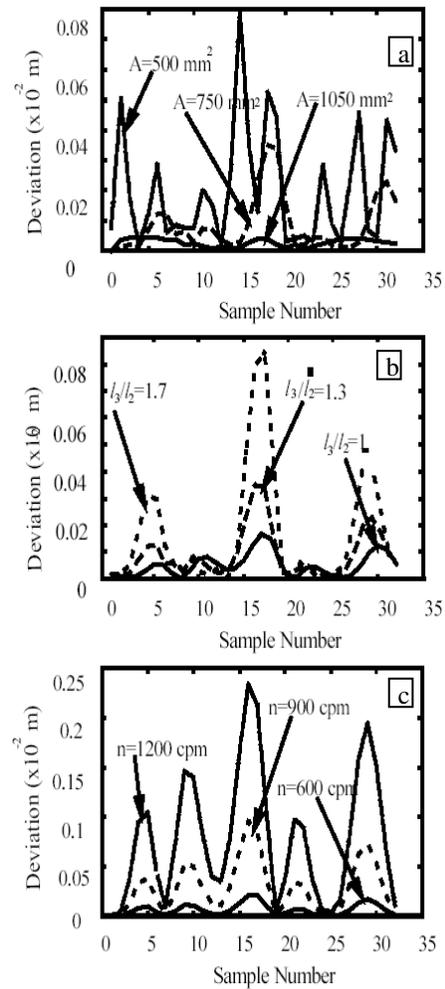between the RB and FB trajectories in the horizontal direction.

Fig.3 Effect of a) cross sectional area, b) ratio of link enghts, and c) speed of cycle on deviations for circular trajectory .

4. CONCLUSIONS

Computer aided design (CAD) techniques are developing very rapidly. Solid modeling, assembly, dynamic analysis, and finite element programs can be successfully used to study the effects of the flexibility in manipulators. In solid modeling and assembly programs input files for the dynamic analysis (Files 1 and 2 given in Section 2) can be created by computer graphics input techniques. CAD programs can be used for the optimal design of manipulators. Condition monitoring by vibration measurement strategies may be developed. Integration of control actions to computer aided mechanical design programs may be done.
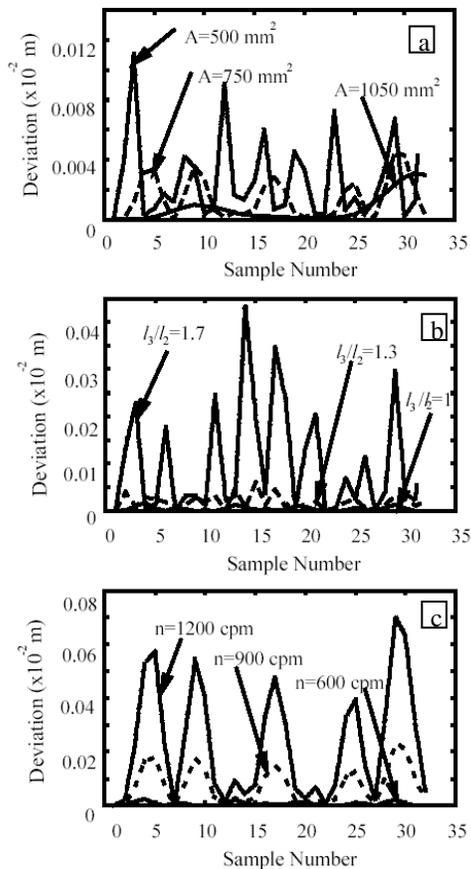
Fig.4 Effect of a) cross sectional area, b) ratio of link lengths, and c) speed of cycle on deviations for linear trajectory.

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