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Design Improvement of Four Bar Linkages Using Different Soft-Computing Methods

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***Abstract:** Modeling of optimized flexible four bar mechanism considering joint clearances are developed at first. The dynamic analysis such as Moment, Torque, Energy and structural analysis such as Deformation, different mode of Stress are done by considering load in coupler point of optimized flexible four bar linkage. The deformation and stress are compared by considering different materials. Lagrange's equation is used to define the direction of the joint clearance. Differential evolution algorithm is used to optimize the length of links which reduce the gap between the desirable and actual path.*

***Keywords:** Optimized linkage; dynamic and structural analysis; Lagrange's equation; differential evolution*

I. INTRODUCTION

A system having no clearance is assumed as rigid link and having clearance is the flexible linkage. An external force is applied on the linkage. Due to the given external force, clearance affects the mechanisms. In a dynamically balanced body, the elastic deformation with high input speed affects the mechanism.

Erkaya and I. Uzmay [1] represented that how the joint clearance affect the path and transmission angle and the link parameters were optimized by the help of GA technique in the 4-bar linkage. S.D.Yu and W. L. Cleghorn [2] represented the dynamic behavior of 4-bar linkage according to the critical running speed and conditions by which the system gets balanced is obtained experimentally and validate with the analytical value. H.Sen Yan and R.C. Soong[8] designed and verified mechanism with its desired position, expected motion and dynamically balanced with considering two conditions i.e. link with different positions and mass distributed in each link.

In this paper, the dynamic and structural analysis is done are compared with considering different materials. Stress analysis of the model is done with the help of ANSYS workbench. The 4-bar linkage with joint clearances is analyzed dynamically with the help of ADAMS by considering the same as for the stress analysis. The results of dynamic and structural analysis of the flexible 4-bar linkage are compared with mechanism before optimization and mechanism after optimization.

II. MODELLING OF THE FOUR BAR MECHANISM:

(a) Design of Joint clearances:

Joint clearance in the flexible 4-bar mechanism is defined as the space between the pin center to the hole centre. Joint clearance acts same as the journal bearing in which pin act as a journal and hole act as a bearing. In an operating condition, pin gives the impact force on the surface of the hole. The impact force between pin and hole surface is tangential in nature.

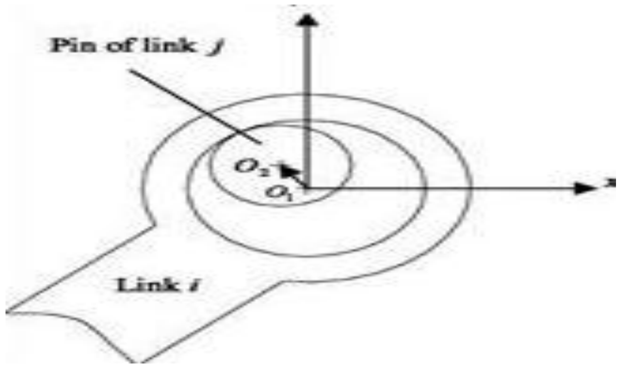

Fig.2.Schmatic diagram of a 4-bar flexible linkage considering joint clearances

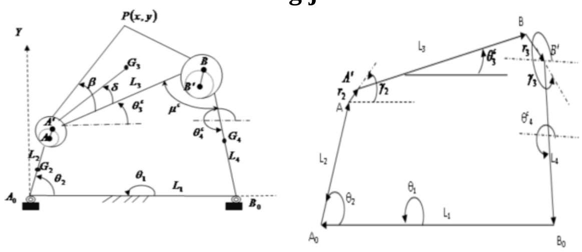

Fig.3.Vector representation of four bar flexible mechanism

(b) Design model of four bar mechanism before optimization:

Cconsidering the link lengths considering joint clearances at crank-coupler and coupler-follower the flexible 4-bar linkage model is developed [1]. The mechanism was solved by using the Equation of Lagrange and Differential Evolution algorithm (DE).

By using the vector loop equation [11], θ_3^c and θ_4^c are obtained which is given below:

$$L_1e^{i\theta_1}+L_2e^{i\theta_2}+L_3e^{i\theta_3}+L_4e^{i\theta_4}+r_2e^{i\gamma_2}+r_3e^{i\gamma_3}=0$$

(1)

θ_3^c and θ_4^c are obtained by using the below equation:

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$$\theta_3^c = 2\tan^{-1}\left(\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}\right) \quad (2)$$

$$\theta_4^c = \cos^{-1}\left(\frac{L_1 - L_2\cos\theta_2 - r_2\cos\gamma_2 - L_3\cos\theta_3^c - r_3\cos\gamma_3}{L_4}\right)$$

(3)

Where A,B and C are:

$$A = -(L_1 + L_3)(2L_2\cos\theta_2 + 2r_2\cos\gamma_2) + 2r_3\cos\gamma_3 + 2L_2 r_2\cos(\theta_2 - \gamma_2) \quad (4)$$
$$+ 2L_2 r_3\cos(\theta_2 - \gamma_3) + 2r_2 r_3\cos(\gamma_2 - \gamma_3) + 2L_1L_3 + L_1^2 + L_2^2 + L_3^2 - L_4^2 + r_2^2 + r_3^2$$

$$B = 4L_3(L_2\sin\theta_2 + r_2\sin\gamma_2 + r_3\sin\gamma_3) \quad (5)$$

And $C = (L_3 - L_1)2L_2\cos\theta_2 + 2r_2\cos\gamma_2 + 2r_3\cos\gamma_3 + 2L_2r_2\cos(\theta_2 - \gamma_2) + 2L_2r_3\cos(\theta_2 - \gamma_3)$
$+ 2r_2r_3\cos(\gamma_2 - \gamma_3) - 2L_1L_3 + L_1^2 + L_2^2 + L_3^2 - L_4^2 + r_2^2 + r_3^2$ (6)

$$\sum_{i=2}^{4}\left[\begin{matrix} I_i\ddot{\theta}_i^c \dfrac{\partial\theta_i^c}{\partial\gamma_2} + m_i\left(\ddot{x}_{Gi}^c \dfrac{\partial x_{Gi}^c}{\partial\gamma_2} + \ddot{y}_{Gi}^c \dfrac{\partial y_{Gi}^c}{\partial\gamma_2}\right) + \\ g m_i \dfrac{\partial y_{Gi}^c}{\partial\gamma_2} + C_{\theta i}\dot{\theta}_i^c \dfrac{\partial\theta_i^c}{\partial\gamma_2} + C_{\gamma_2}\dot{\gamma}_2 \end{matrix}\right] = 0$$

The Lagrange's equation by which the original link was optimized: (7)

Similarly, the direction of γ_3 is determined using above equations.

The gap which is shown in betwixt the desirable and actualized path is attenuated with the aid of the equation given below.This gives the optimized link lengths:

$$Minimize F(x) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[\left(Px_d^i - Px_g^i\right)^2 + \left(Py_d^i - Py_g^i\right)^2\right]}$$

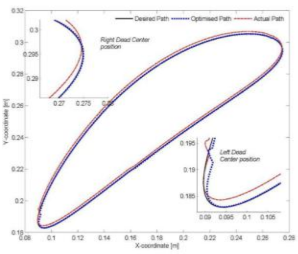
(9)

Subject to $h_j(x) \le 0, x_l \le x_j \le x_u$,

Where N = number of targeted points

The different dynamic parameters required for the analysis [1] are in the table-1 given below.

After optimization using differential evolution algorithm, the gap between the actual and desired path is reduced which is shown in the figure (4, 5, and 6)?



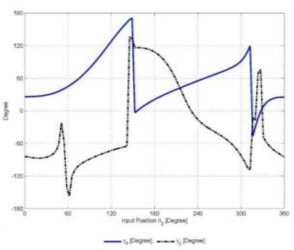


Fig.4. Coupler curve with 1mm clearance at two points

Fig. 5.Position of joint clearance with respect to orientation of input link

DESCRIPTION	PARAMETERS	VALUES
MOI of link 2	I_2	$5.12\times10^{-4} Kgm$
MOI of link 3	I_3	$8.85\times10^{-3} Kgm$
MOI of link 4	I_4	$1.58\times10^{-3} Kgm$
Mass in link 2	m_2	$0.121 Kg$
Mass in link 3	m_3	$1.048 Kg$
Mass in link 4	m_4	$0.071 Kg$
Gravitational acceleration	g	$9.8 m/s^2$
Input angular velocity	ω_2	$62.83 rad/s$
Damping coefficient	$C_{\gamma^2}, C_{\gamma^3}$	$0.2\times10^{-6} Kgms$

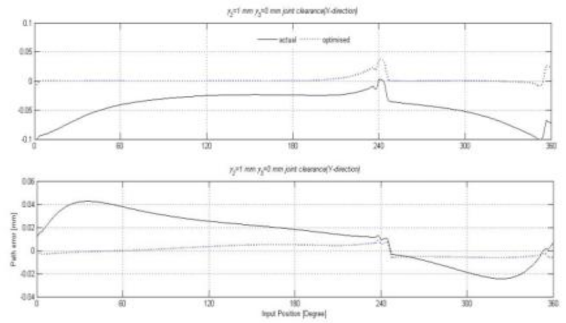


Fig. 6. Path error between desired with actual and optimized mechanism

After optimization the optimized values of design variables obtained which is mentioned in table no.2

TABLE 2: Optimized design variables

First Clearance	1mm
Second Clearance	1mm
L_1 **(mm)**	401.0481
L_2 **(mm)**	101.0600
L_3 **(mm)**	361.9587
L_4 **(mm)**	249.2171
β **(degree)**	18.7884
$A'P$ **(mm)**	304.1872

(c) Modeling of four bar mechanism after optimization:

I. Modelling of Mechanism in ADAMS

The 4-bar mechanism is modeled using ADAMS considering the link lengths which are obtained after optimization [table no. 2]. At the coupler point a load of 10kN is applied.Here dynamic analysis is done by using ADAMS .Analysis is done by taking point load at coupler point and input angular velocity of 62.83rad/sec. Using post processor window result is analyzed.

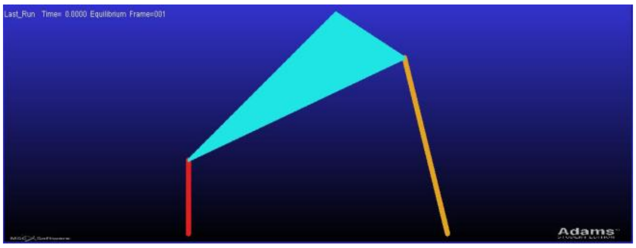


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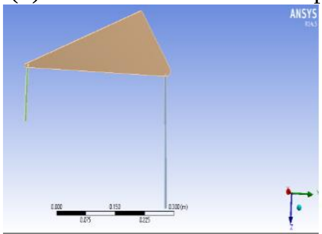
Fig.7. 4-bar model in ADAMS

II. Using ANSYS

The 4-bar linkage is modeled in Catia V5 and the same model is imported in Ansys workbench for structural analysis. Ansys is widely used in all type of simulation. Here the model is imported in the static structural mode and then all the boundary condition is applied on it. Further the loading condition is given to the model. It gives the deformation, different mode of stress of the system.

The total deformation and von-misses stress are analyzed and the system is compared with different materials that are steel, Al, gray cast iron and composite whose results are given below:

(1) Total Deformation before optimization
(2) Total deformation after optimization
(3) Von-misses Stress or Equivalent Stress before optimization
(4) Von-misses stress after optimization



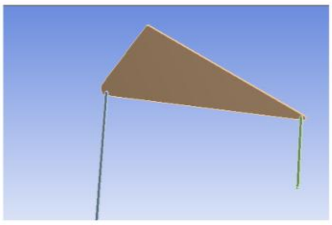


Fig. 8. Four bar model in Ansys before optimization Fig. 9. Four bar model in Ansys after optimization.

Overall Deformation before optimization

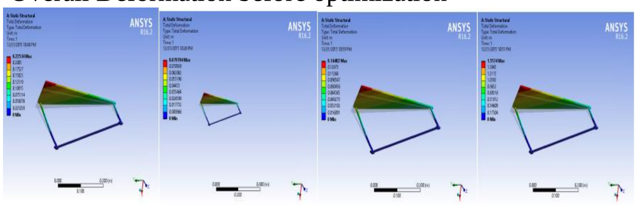


Fig.14. Aluminium Fig.15.Structural Steel Fig.16.Gray Cast Iron Fig.17. Epoxy E Glass

Overall deformation after optimization

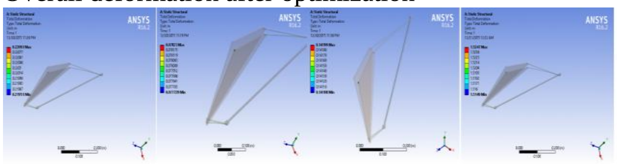


Fig.14. Aluminium Fig.15.Structural Steel Fig.16.Gray Cast Iron Fig.17. Epoxy E Glass

Equivalent Stress before optimization

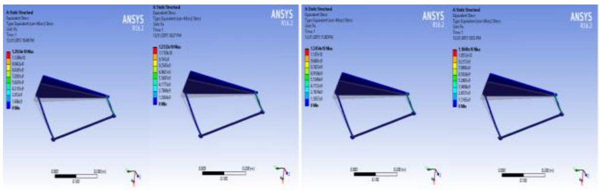


Fig.18. Aluminium Fig.19.Structural Steel Fig.20.Gray Cast Iron Fig.21. Epoxy E Glass

Equivalent stress after optimization

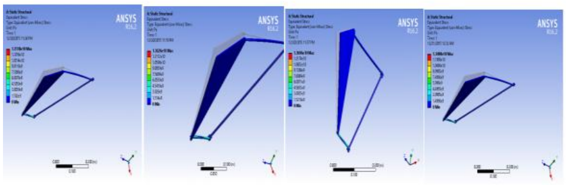


Fig.22. Aluminium Fig.23.Structural Steel Fig.24.Gray Cast Iron Fig.25. Epoxy E Glass

III. RESULTS AND DISUSSION

The four bar flexible model before optimization and after optimization are compared with considering the external load of 10N at the coupler point. Here we analyzed how the system before optimization and after optimization behaves dynamically and structurally. By using Adams the analysis is done for the different parameter. Different materials are taken for comparison of both the models. From the result it is seen that optimized model gives better result .Out off four materials like Aluminium alloy, structural steel, gray cast iron, epoxy E glass composite material used for optimized mechanism gives better result than others under the action of external load in dynamic condition.

TABLE 4: Physical parameters of mechanism and the results of different materials

Physical Parameters	**Types of Materials**			
	Structural Steel	Gray Cast Iron	Al Alloy	Epoxy-Glass
Density(kg m^-3)	7850	7200	2770	2000
Force Applied(kN)	10	10	10	10
UltimateStrength(compressive)inPa	0	8.3e+008	0	-1.3e+008
Yield Strength(Compressive)in Pa	2.5e+008	0	2.8e+008	-1.3e-002
Yield Strength(Tensile)in Pa	2.5e+008	0	2.8e+008	3.6e-003

Ultimate Strength(Tensile)in Pa	4.7e+008	2.5e+008	3.1e+008	3.6e+007
Young's Modulus (Pa)	2.02e+011	1.1e+011	7.1e+010	4.6e+01
Poisson's Ratio	0.3	0.28	0.33	0.3
Maximum Deformation before optimization(m)	0.079794	0.14482	0.22534	1.5574
Maximum Deformation after optimization(m)	0.07823	0.14199	0.22093	1.5247
Minimum Deformation before optimization(m)	0	0	0	0
Minimum deformation after optimization(m)	0.077729	0.14108	0.21951	1.5149
Maximum Von-misses Stress before optimization(Pa)	1.2532e10	1.2454e10	1.2654e10	1.1849e10
Maximum Von-misses Stress after optimization(Pa)	1.3626e10	1.3696e10	1.3518e10	1.3498e10

IV. CONCLUSION

In this paper, the systems are analyzed dynamically and structurally. Here the optimum link lengths are found out with an objective to minimize the error in the path generation considering the given joint clearances. It is observed from the result that after doing optimization the error is reduced between the desired and optimized curve. These results can be seen as appropriate optimization technique for minimizing the actual error in the presence of clearances mechanical condition of the system is better in case of optimized model.

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