DESIGN AND ANALYSIS OF AN EASILY CONTROLLED WALKING ROBOT LEG MECHANISM

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***Abstract* — In this paper, numerous walking and controlling machines and robots have been convened, designed and built in the last fifteen years to open new fields of application. Compared to wheeled vehicles walking machines show the advantage that they can act in highly unstructured terrain without having prepared this terrain in advance by streets or rails. In legged robots cross obstacles more easily; depend less on the surface conditions and quality and, in general, exhibit better adaptability. In this paper a numerical and experimental analyses of a pantograph-leg are presented. In particular, a suitable model of the sample leg has been analyzed and Kinematics and Dynamics have been solved. A parametric study has been also carried out in order to investigate the influence of some basic design parameters on its motion capabilities.**

***Keywords*— Robot Leg, Transient analysis Motion Control System, Solid Works, FEA, ANSYS**

I. INTRODUCTION

In traditional method, most mobile robots have been equipped and operated with wheels. The wheel is easy to control and direct. It provides a stable base on which a robot can makeover and is easy to build. In this method, one of the major drawbacks of the wheel, however, is the limitation it imposes on the terrain that can be successfully navigated. A wheel requires a relatively flat surface on which to operate. Rocky or hilly terrain, which might be found in many applications such as waste clean-up, forestry and planetary exploration, imposes high demands on a robot and precludes the use of wheels.

A second approach to this problem would be to use tracked wheel robots. For many applications this is acceptable, especially in very controlled environments. However, in other instances the environment cannot be controlled or predicted and a robot must be able to adapt to its surroundings.

Such a surrounding can be places where robots would have to step over the obstacles such as a surface where pipes are running and where they have to move on discontinuous path ways terrain like steps.

Research into legged robotics promises to overcome these difficulties. The complexity of control required for a legged robot to navigate autonomously over unfamiliar terrain has made them difficult to build.

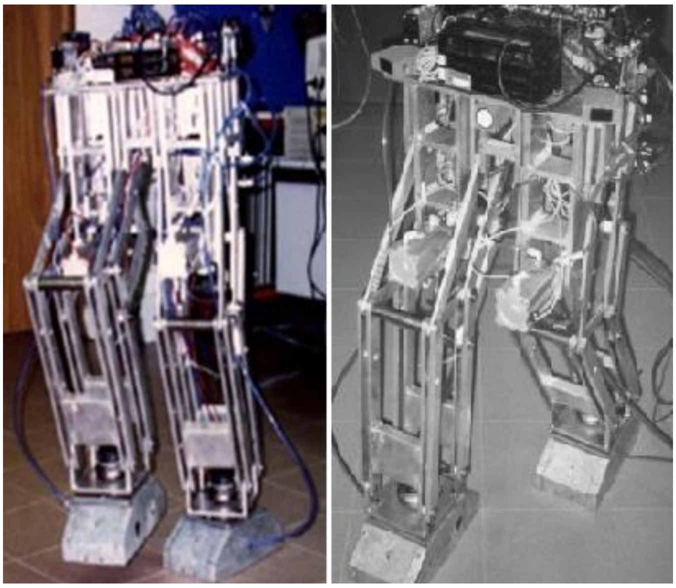

Fig. 1 Prototype model of Ep WAR II at laboratory of robotics of Mechatronics in cassino

Recent developments in embedded controller technology have yielded very sophisticated computing devices in relatively small, easily programmed modules. With these advanced components, it is now possible to control relatively complex and sophisticated devices.

II. RELATED WORK

Hirose S, Kunieda O Generalized [2], Standard Foot Trajectory for a Quadruped Walking Vehicle. In this paper a comparative study of continuous and discontinuous gaits with regard to their maximum achievable velocity and stability. Other aspects such as implementation in real machines, power requirements, and control under terrain difficulties are mentioned briefly. An elemental discontinuous gait is stated, and some variations on deriving crab and turning gaits are performed. Different methods for enlarging the achievable crab angle and improving stability are discussed for discontinuous crab gaits

Song S. M., Lee J. K, Waldron K.J.[4] Motion Study of Two and Three Dimensional Pantograph Mechanisms, In this paper, the mechanical efficiency of kinematics of Pantograph type manipulators are studied. The mechanical efficiency of pantograph mechanism and conventional open-chain and closed chain manipulators are studied and evaluated using the concept of modified geometric work.
The kinematics of 6 d.o.f .., pantograph type manipulators are studied and special mechanisms are introduced.

III. SYSTEM DESIGN

In this paper, a study of feasibility for a fully rotating actuation of the pantograph- leg has been carried out. In particular, in this project the numerical analysis of a one-degree of freedom (DOF) leg mechanism for walking machines will be presented. A suitable model of the leg has been analyzed and a simulation of Kinematics and Dynamics has been carried out.

In particular, the motion capability of the leg has been studied, together with theoretical acceleration, velocity and forces. A parametric study has been also carried out in order to investigate the influence of some basic design parameters on motion capabilities of the leg. The aim is to build a 6-legged walking machine capable of a straight walking on various terrains with only 2 actuators.

Many interesting walking machines have been presented, see for example [7~8]. One of the main objectives is to achieve a walking operation, without the need of an external power supply or connection to an external control unit. One way to get this target is to build lighter and simpler architectures, and reducing the number of DOF, [9].

Furthermore, the basic considerations for a leg design are as follows: the leg should generate an approximately straight-line trajectory for the foot with respect to the body [10~11]; the leg should have an easy mechanical design; if it is specifically required it should posses the minimum number of DOF to ensure the motion capability. Among many different structures, we consider a leg mechanism based on the Chebyshev design [12~13].

The proposed leg mechanism is schematically shown in Figure 2. In particular, its mechanical design is based on the use of a four-bar linkage, a five-bar linkage, and a pantograph mechanism.

The four-bar-linkage ensures an approximately straight line trajectory; meanwhile the pantograph mechanism is used to amplify the trajectory generated by point B. The five-bar linkage in the mechanism is used in order to obtain suitable motion capabilities. For such mechanism, the leg motion can be performed by using 1 DOF.

Kinematic performance

Several solutions can be used to obtain the desired trajectory of point B, for example by designing a proper cam profile, [13] or using pneumatic actuation, as described in [5~6]. In this paper we propose a solution to consider a fully rotational actuation at point L to obtain the suitable trajectory of point B.

Furthermore, the trajectory of point B, and consequently, point A can be suitably modified by changing the design parameters shown in Figure 2. In particular, it will be shown that better features can be obtained if the transmission angles _1 and _2 have suitable values. A parametric study has been also carried out to study the influence of P and H parameters on the motion capabilities of the 1-DOF leg.

The Kinematic analysis has been carried out in order to evaluate and simulate the performance and operation of the leg system.

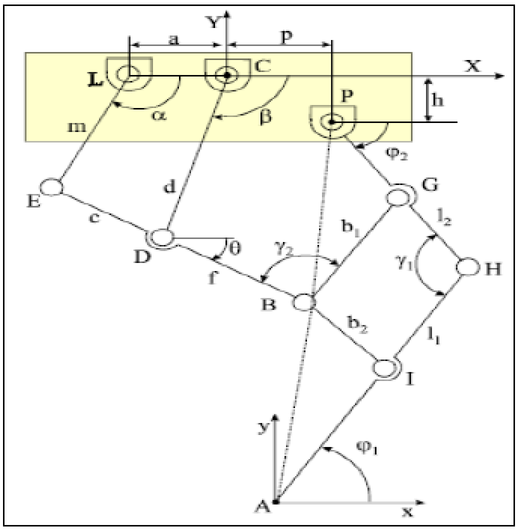

Fig. 2 DOF paragraphed leg

In particular, the mechanical design is based on the Chebyshev design [1~3], which can trace a coupler curve of point B with a straight-line and circular segments.

In order to investigate the motion capabilities of the 1-DOF leg two reference systems have been considered. Frame CXY is fixed on the body and frame A xy is fixed on the extremity point A of the leg. Indeed, the position of point B with respect to CXY frame can be evaluated.

Dynamic performance

The walking performance can be also evaluated from dynamic viewpoint by using the Principle of Virtual Power to obtain the force acting on the body of the leg as a function of the actuating torque 'τ' when friction is neglected. A suitable model for the dynamic analysis is shown in Figure 3. The force acting on the body of the leg can be evaluated in the form

$$F = \tau w / (-x \sin\varphi_2 + y \cos\varphi_2)$$

Where the involved velocities can be computed as a function of the input crank velocity 'ϖ'

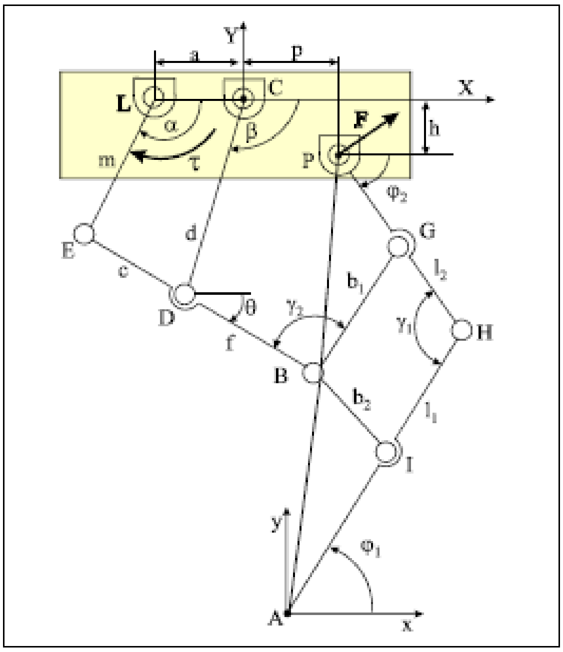

Fig. 3 Dynamic Analysis

Consequently, the component $F\ x$ is useful for forward motion of the body of the walking machine and $F\ y$ gives its load capacity. They can be evaluated in the form

$$F_x = Sin\ \varphi_2$$
$$F_y = Cos\ \varphi_2$$

IV. MODELING OF ROBOTIC ARM

The parametric study of the mechanism has been conducted to obtain the required trajectory of the proposed mechanism for a walking robot leg. The numerical analysis has been simulated by using MAT LAB as well with SOLID WORKS software.

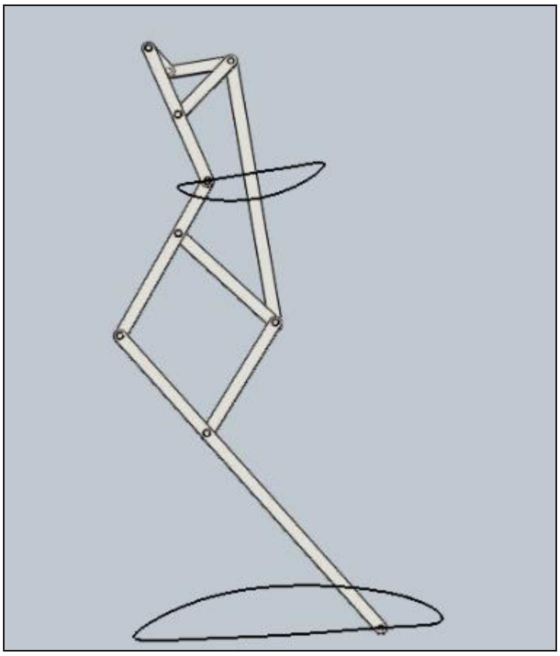

Fig. 4 Designed Robotic Leg

Initially the mechanism is simulated for the crank speed of 22rpm. At this speed the reference point A of the mechanism displacements, velocities & accelerations have been found by considering the links are elastic members with the help of ANSYS.

These values obtained by ANSYS are found to be negligible when compared with the reference point A of the mechanism displacements, velocities and accelerations that are found by using MATLAB/ SOLIDWORKS when the links are considered as rigid members

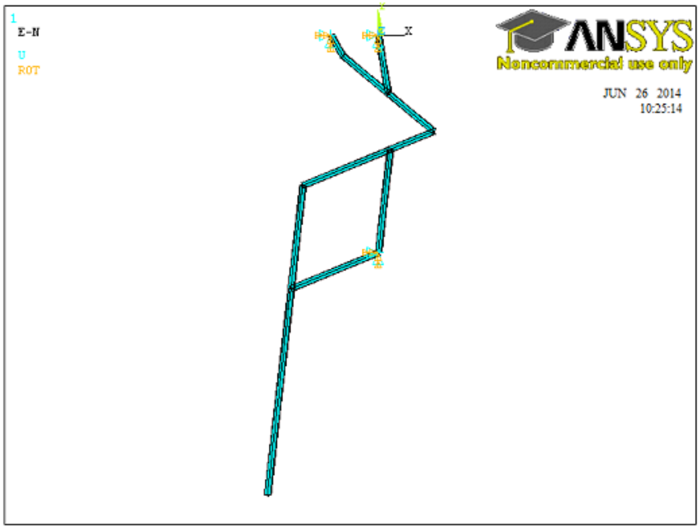

Fig. 5 FE-MODEL CREATED IN ANSYS FOR ROBOT LEG

V. RESULTS

The speed of the crank is increased in steps of two times, three times, four times and five times. Finally it has been observed that for the crank speed at five times i.e., at 110rpm the elastic displacements, velocities and accelerations found by ANSYS are comparable with the rigid body displacements, velocities and accelerations found by SOLIDWORKS.

Hence this mechanism can run up to 110 rpm crank speed so that the inertia effect will not affect the performance of the mechanism.

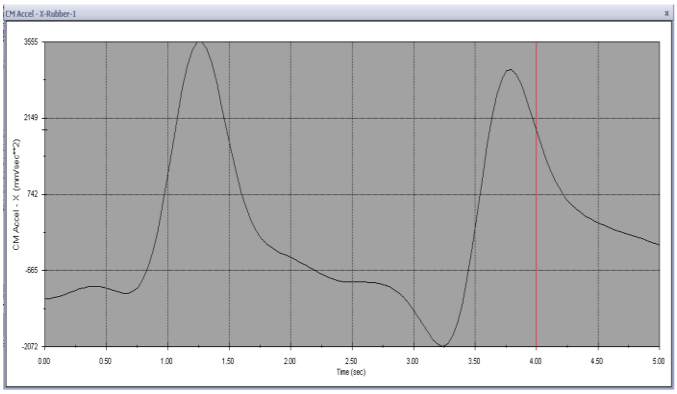

Fig. 6.1 NUMERICAL SIMULATION OF ACCELERATION (MM/SEC^2) AT 22 RPM IN X- DIRECTION AT POINT A

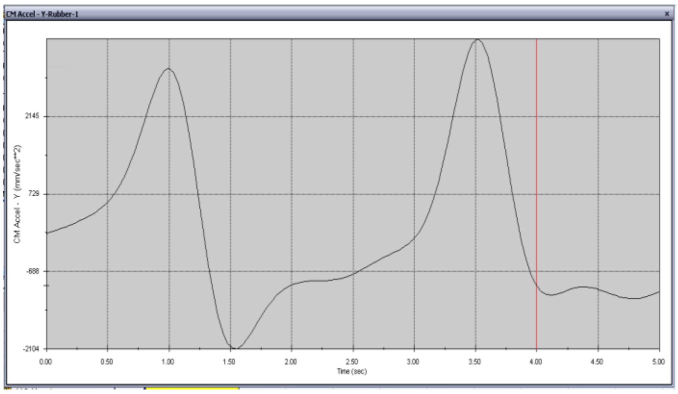

Fig. 6.2 NUMERICAL SIMULATION OF ACCELERATION (MM/SEC^2) AT 22RPM IN Y- DIRECTION AT POINT A

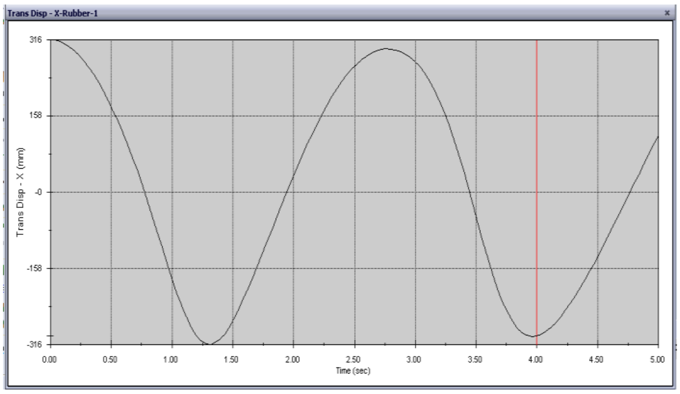

Fig. 6.3 NUMERICAL SIMULATION OF DISPLACEMENT (MM) AT 22RPM IN X- DIRECTION AT POINT A

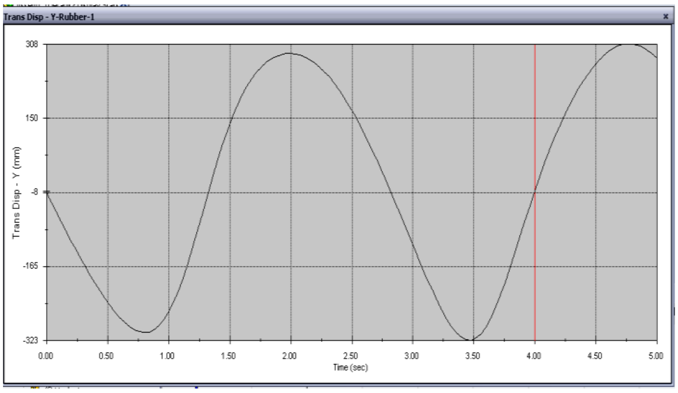

Fig. 6.4 NUMERICAL SIMULATION OF DISPLACEMENT (MM) AT 22RPM IN Y- DIRECTION AT POINT A

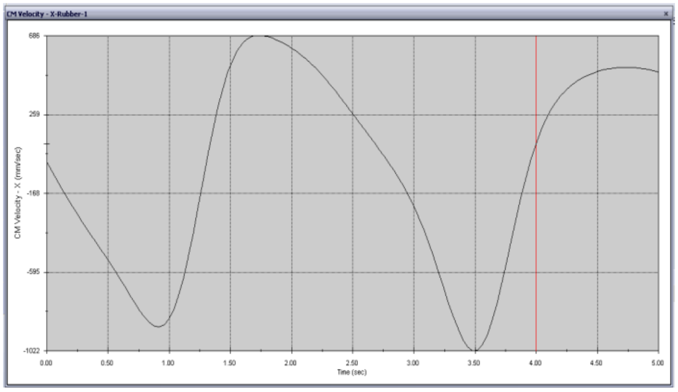

Fig. 6.5 NUMERICAL SIMULATION OF VELOCITY (MM/S) AT 22RPM IN X- DIRECTION AT POINT A

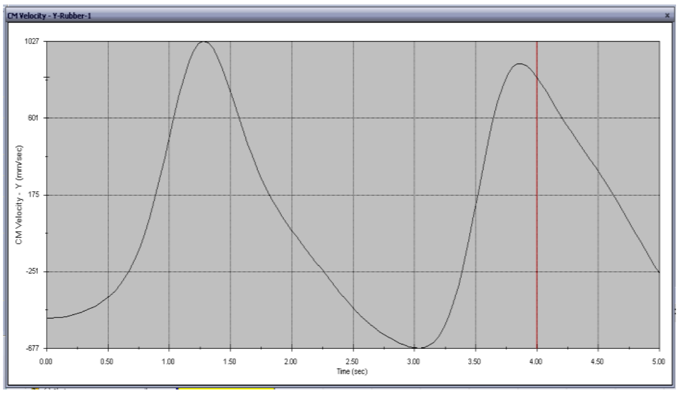

Fig. 6.6 NUMERICAL SIMULATION OF VELOCITY (MM/S) AT 22RPM IN Y- DIRECTION AT POINT A

A physical model of Robot Leg Mechanism can be prepared and inspected experimentally to check its performance by increasing the crank input speed. Feed back control system can be incorporated to make sure the required trajectory of the mechanism at higher speed remains unaffected. Traction force due to contact between foot and ground and Friction at joints can also be incorporated in the analysis.

TABLE I
CHEBYSHEV MECHANISM

The coordinates of the joint positions have been tabulated in the following table which will be required to do the analysis by using ANSYS.

Angle α^0	Chebyshev Mechanism					
	1		2		3	
	X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)
30	-28.39	-12.5	10.25	-61.45	48.85	-110.8
330	-28.34	12.5	-38.6	-49.15	-48.85	-110.8
60	-37.5	-21.65	10.56	-61.6	58.63	-101.55
180	-75	0	-37.5	-50	0	-100
360	-25	0	-12.5	-61.23	0	-122.47

TABLE III
PANTOGRAPH MECHANISM

Angle α^0	Pantograph Mechanism							
	4		5		6		7	
	X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)
30	-0.28	-120	-98.58	-138.38	-98.29	-248.38	-97.71	-468.38
330	-77.41	-151.85	-134.5	-233.93	-57.1	-312.08	69.43	-489.55
60	12.44	-120.7	-79.92	-159.01	-92.37	-268.31	-117.26	-486.89
180	-41.37	-128.07	-124.1	-184.23	-82.74	-286.15	0	-490
360	-49.16	-131.59	-147.5	-149.84	-98.32	-248.24	0	-445.05

TABLE IIIII
DISPLACEMENT

DISPLACEMENT OF POINT A ALONG		
	X-DIRECTION (M)	Y-DIRECTION (M)
R.P.M	From solid works	From solid works
22	0.117	0.207
44	0.117	0.207
66	0.117	0.207
88	0.117	0.207
110	0.117	0.207

TABLE IVV
VELOCITY

VELOCITY OF POINT A ALONG		
	X-DIRECTION(m/sec)	Y-DIRECTION (m/sec)
R.P.M	From solid works	From solid works
22	0.284	0.308
44	0.569	0.617
66	0.853	0.925
88	1.125	1.321
110	1.42	1.502

TABLE V
ACCELERATION

ACCELERATION OF POINT A ALONG		
	X-DIRECTION (m/sec2)	Y-DIRECTION (m/sec2)
R.P.M	From solid works	From solid works
22	1.11	2.554
44	4.421	10.27
66	9.994	22.883
88	13.569	30.789
110	27.708	64.185

VI. CONCLUSIONS

The parametric study of the mechanism has been conducted to obtain the required trajectory of the proposed mechanism for a walking robot leg. The numerical analysis has been simulated by using MAT LAB as well with SOLID WORKS software.

The speed of the crank is increased in steps of two times, three times, four times and five times. Finally it has been observed that for the crank speed at five times i.e., at 110rpm the elastic displacements, velocities and accelerations found by ANSYS are comparable with the rigid body displacements, velocities and accelerations found by SOLIDWORKS. Hence this mechanism can run up to 110 rpm crank speed. If the mechanism is allowed to operate beyond this speed the required path trajectory will not be followed accurately and also the jerks might be occurred in the mechanism.

SCOPE OF FUTURE WORK

A physical model of Robot Leg Mechanism can be prepared and inspected experimentally to check its performance by increasing the crank input speed. Feed back control system can be incorporated to make sure the required trajectory of the mechanism at higher speed remains unaffected. Traction force due to contact between foot and ground and Friction at joints can also be incorporated in the analysis.

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