DEFLECTION CHARACTERISTICS OF REDUNDANT ROBOTS

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1. ABSTRACT

The redundant robots analyzed here have large numbers of degrees of freedom. Such robots are analogous to snake or tentacles and are useful for operation in highly constrained environments and novel forms of locomotion- here it has been defined as critical manipulation. In this paper the end point deflection of hyper-redundant robots have been studied by parameterization of the flexible links of the robot manipulator. A number of configurations of the redundant manipulator were taken into consideration for the present study and the configuration which gives minimum end point deflection has been recommended for the critical manipulation.

2. INTRODUCTION

The main use of redundant robots is in manipulation tasks requiring high dexterity, which is being defined as critical manipulation tasks. Such as doing any inspection operations, inside a bent pipe or a contour, inside the space station-shuttle, repair or maintenance work in or outside aircraft, sometimes become critical. It is very difficult to get this type of work done by using conventional robot manipulators having 6 degrees of freedom. For this reason extra degrees of mobility are to be added to the robot manipulators. This of course makes the system more complex in the sense that more joints are needed, more motors are to be mounted and control becomes more complex. But for certain tasks this is a necessity and it cannot be avoided. The best we can do is to make the system configuration such that the problem of accurate positioning becomes less complex. The present analysis is a step towards that goal.

It is known that structural optimization can result in robotic arms with significantly improved stiffness and load carrying capacity. In [1] it has been shown that the geometrical shape of

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the manipulator links can be optimizing for maximum stiffness-to-weight and strength-to-weight ratios. Here the problem of strengthening a manipulator has been solved by optamizing the redistribution of reliable material without increasing the total mass of the manipulation.

Some significant analysis on hyper-redundant robot mechanisms has been made in [2]. The authors here suggested that their methods can be applied to a wide variety of hyper-redundant morphologies and lead to efficient inverse kinematic, path planning, obstacle avoidance, locomotion and grasping schemes. Some applications of redundant robots have been discussed in [3,4].

Recently NASA's Kennedy Space Center is considering the design of redundant robots capable of reaching inside the Space Shuttle cargo bay. It is supposed to take pictures of the satellite that is loaded in the cargo bay. Also, it is supposed to turn switches, on and off, on the satellite. There is very little room and therefore, it is desirable to mount as little sensors as possible on the robot.

Following this tasks as a guide, the present investigation has been carried out for finding the effect of end point deflection and radius of curvature on the design configuration of the flexible links of the manipulator. The ANSYS software program has been used for the present study.

3. KINEMATICS OF PLANER HYPER-REDUNDANT MANIPULATORS:

A planar hyper-redundant manipulator may be comprised of many flexible of rigid links as shown in figure 1. It has been

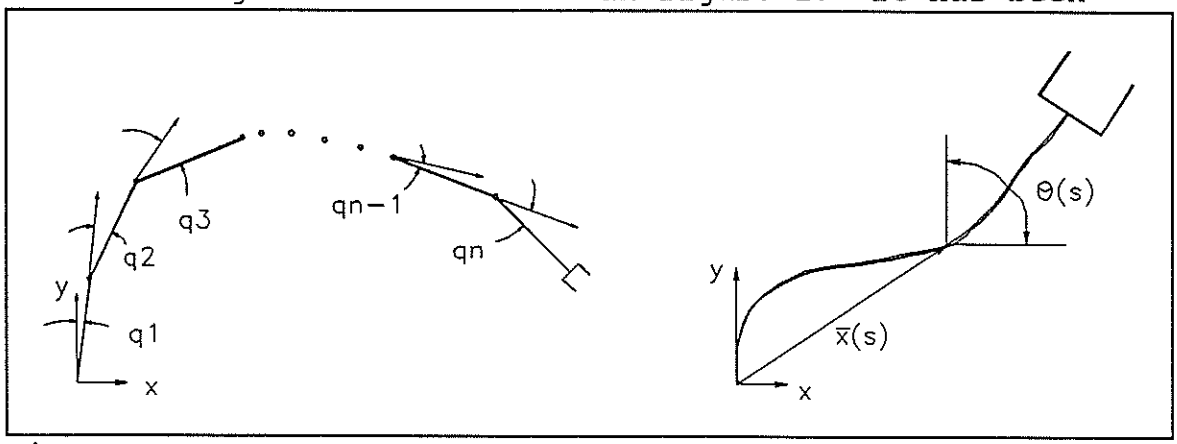


Figure 1

assumed that the geometric features of a hyper-redundant manipulator can be captured by a "back bone curve", of constant length, which lies along the center line of the hyper-redundant manipulator. the backbone curve is the locus of all points in the base frame which have position defined by:
S is the backbone curve arc length, measured form the origin, and it is assumed that all lengths in the plane are scaled to units of

$$\bar{x}(s) = [x_1(s), x_2(s)]^T \tag{1}$$

the constant manipulator length so that 's' is in the range $0 \leq s \leq 1$. It is possible to define the 'curvature function' as:

$$k(s) = \left| \frac{d^2\bar{x}}{ds^2} \right| \tag{2}$$

which totally defines the shape of a planar curve. If we assume that equation 3 holds and that the tangent to the backbone curve at its base point is in the x_2-direction; that is it follows equation 4. Then the curve can be paramertized as follows:

$$\bar{x}(0) = \bar{0} \tag{3}$$

$$\frac{d\bar{x}}{ds} = [01]^T \tag{4}$$

$$x_1(s) = \int_0^s \sin\theta(\sigma)\, d\sigma \tag{5}$$

$$x_2(s) = \int_0^s \cos\theta(\sigma)\, d\sigma \tag{6}$$

where:

$$\theta(s) = \int_0^s k(\sigma)\, d\sigma \tag{7}$$

$$\theta(s_0) \tag{8}$$

Equation 8 is the angle which the tangent to the curve at $s=s_0$ makes with the tangent at the point $s=0$ measured clockwise. The formulation is quite general if the curvature function depends upon time as well as arc length.

For hyper-redundant manipulators the real complexity arises when solving the inverse kinematics problem. One method, based on a modal expansion of the curvature function has been discussed in [4]. This method could be used for trajectory planning purposes in the same way that inverse kinematics algorithms are used as the basis for planning joint trajectories of non-redundant manipulators.

However, to help simplify the complexity of inverse kinematics

problem a new approach has been taken here. Four different configurations have been explored and their end point deflection characteristics have been analyzed. The configuration with minimum end point deflection will be considered for critical manipulation.

4. ANALYSIS ON DIFFERENT CONFIGURATIONS:

It has been proposed that four basic types of configurations will be suitable for any kind of critical manipulation. The configurations are shown in figure 2. We are calling them

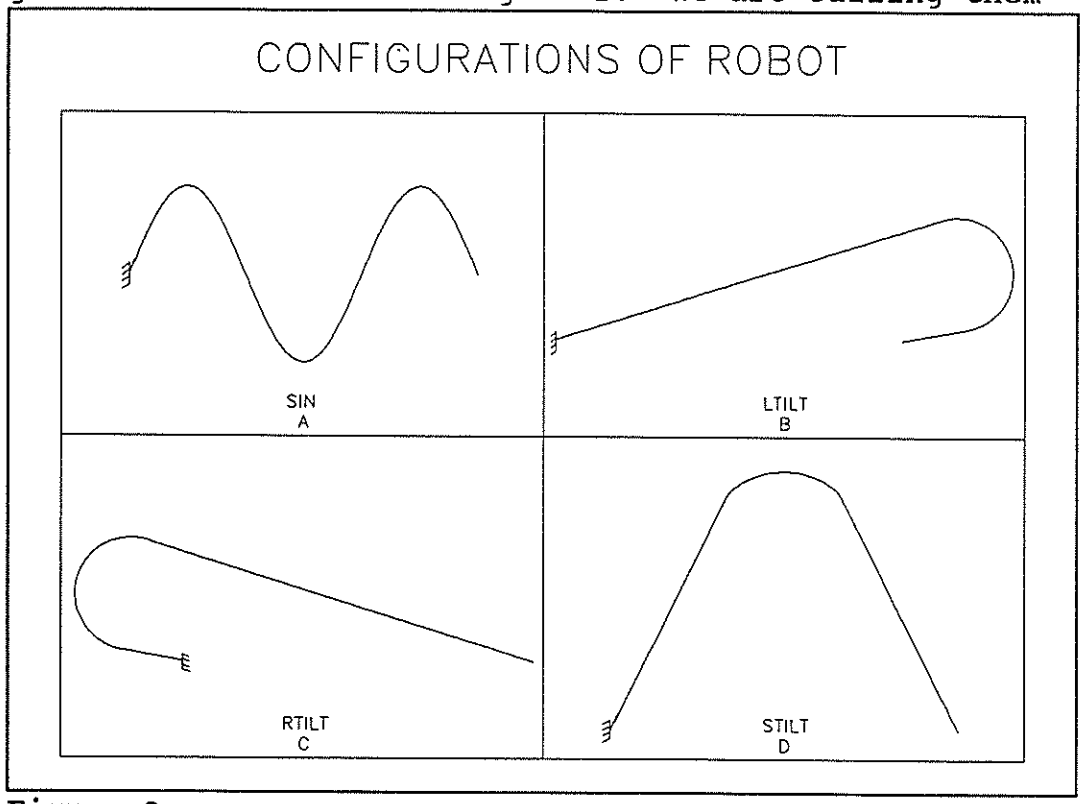


Figure 2

SIN, LTILT, RTILT, and STILT. Configuration SIN is like a sine curve, the LTILT configuration manipulates towards it's fixed base point, the RTILT configuration manipulates away from it's fixed base point, and the STILT configuration manipulates between the fixed base and the end point. With these four types of configurations the following studies have been performed for uniform loading caused by gravity. For simplification other external active forces have not been considered here.

1. For the same weight per unit length of the rectangular cross-section, the end point deflections have been studied with radius of curvature for a given reachability for all configurations. The results are shown in figure 3. It is seen that RTILT is most vulnerable with respect to end point deflection, comparatively less for LTILT. The end point deflection is further decreased for the cases of STILT and SIN. The same study has been performed with increased reachability and the results have been

shown in figure 4 and figure 5.

2. For the same weight per unit length the end point deflections have been studied with respect to the radius of curvature for circular cross-section, whose diameter is equal to the height of the rectangular cross-section, for a given reachability for all the configurations. The results have been shown in figure 6. The same study has been performed with increased reachability step by step. The results are shown in figure 7 and figure 8.

5. RESULTS AND DISCUSSION:

Figure 3 shows for a given end point reachability (3 meters), that the SIN configuration gives lowest end point deflection. Next, lower end point deflection has been noticed for STILT, LTILT and RTILT in increasing order. But when the radius of curvature is increased, SIN configuration becomes vulnerable with respect to deflection, while STILT shows indifferent characteristics towards increase of the radius of curvature. Similar characteristic features have been shown for the LTILT configuration. However, when the reachability is increased step by step (figure 4 and figure 5), it has been seen that the end point deflection for RTILT rapidly decreases; but the characteristics of the LTILT, STILT and SIN configurations show that the end point deflections are indifferent with respect to the increase in radius of curvature, while maintaining the same initial end point deflection pattern. (i.e. end point deflection of SIN < STILT < LTILT < RTILT.

The same characteristics (i.e. end point deflection versus radius of curvature for different configurations) have been studied in a similar way with circular cross-sections. The LTILT configuration showed the minimum end point deflection with monotonically increasing pattern followed by SIN, STILT, and RTILT in an increasing order. But with increasing reachability (figure 7 and figure 8) the LTILT and SIN configurations overlap and show almost similar characteristics.

6. RECOMMENDATIONS:

Some very important recommendations about the configurations of hyper-redundant manipulators can be made from the above observations.

- It is much easier to select a backbone curve from the four configurations for critical manipulation rather than solve the inverse kinematics of the manipulator.

- The radius of curvature of a particular configuration satisfying the required reachability constraints is to be selected form the above characteristics (reference figure 3 - figure 8) which gives minimum end point deflection.

- Some relative suggestions can be made from the above

analysis:

i) For rectangular cross-sections, it is always better to use the SIN configuration with lower radius of curvature, for shorter reachabilty.

ii) For rectangular cross-sections, however, if the environment constraint permits, either a SIN or STILT configuration can be selected as the backbone curve.

iii) For circular cross-sections, if the environments (for manipulation) permit, LTILT configuration is to be selected as the best choice. But if shorter reachabilty is desired the SIN configuration should be selected for shorter radius of curvature.

iv) However for circular cross-sections and for higher reachability any one of the configurations "SIN, LTILT and STILT" can be chosen, because they show almost similar end point deflection characteristics.

7. CONCLUSION:

The end point deflection characteristics of four different redundant manipulation configurations have been studied using the ANSYS software. Some useful recommendations have been made for optamizing the shape of a particular configuration for minimum end point deflection. Note that for the present, analysis the joint compliance has been ignored for simplification purposes. Future work will be carried out taking into account joint compliance for studying the deflection characteristics of the SIN, LTILT, RTILT, and STILT configurations.

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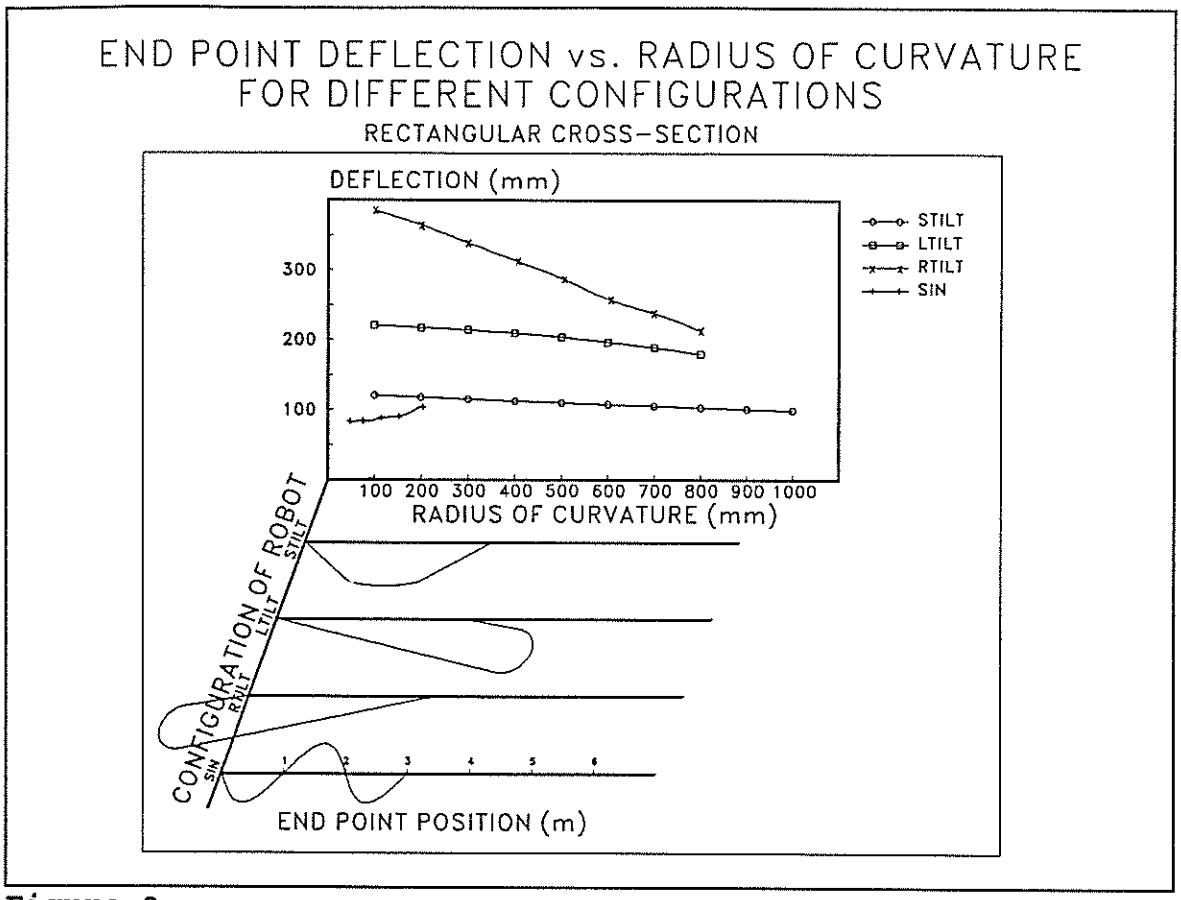


Figure 3

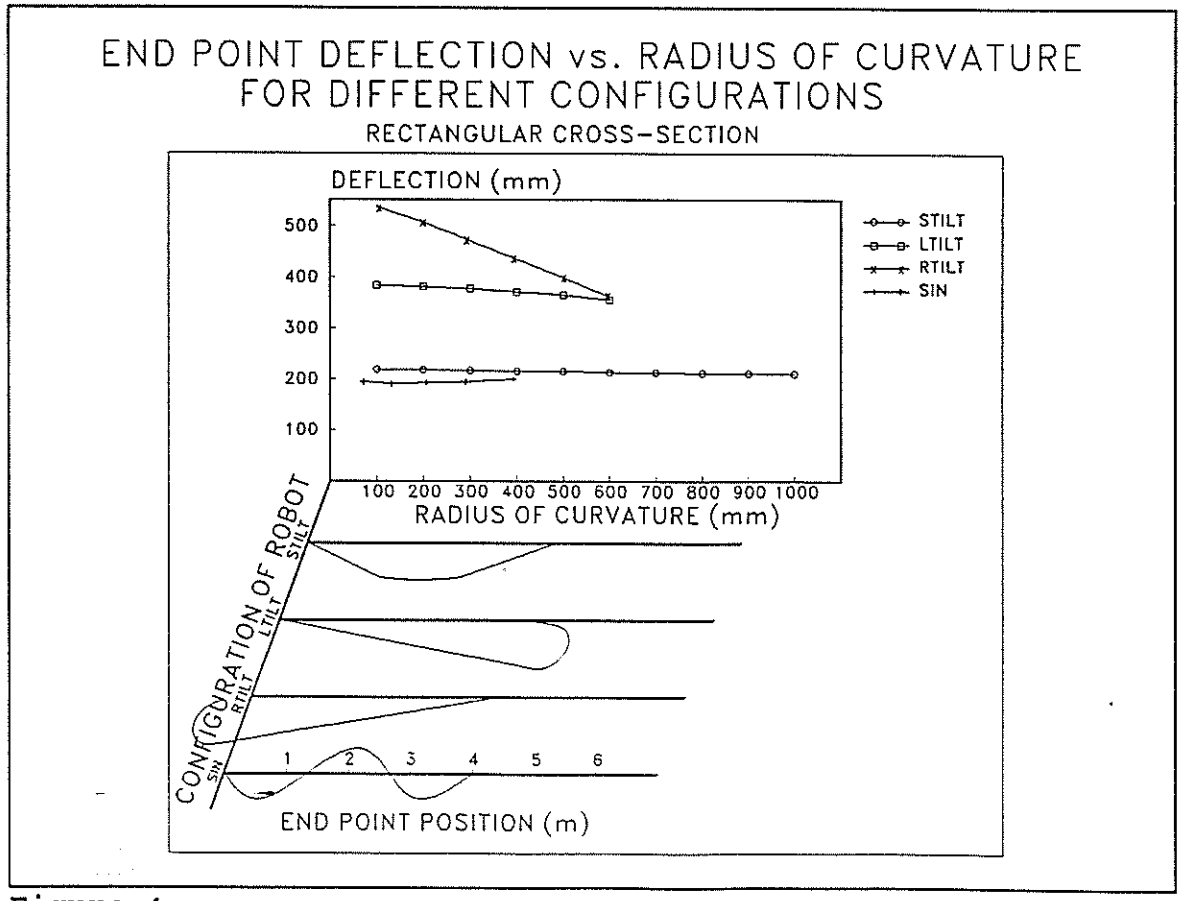


Figure 4

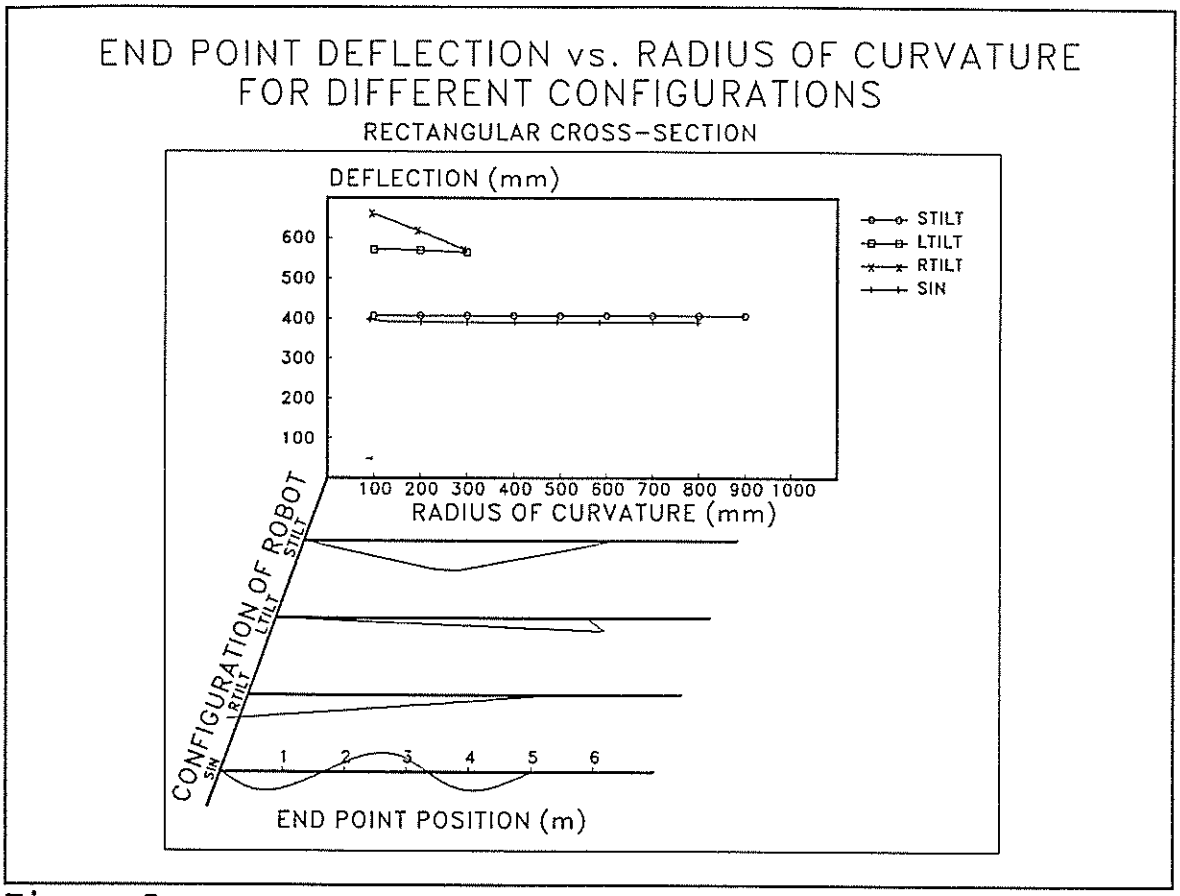


Figure 5

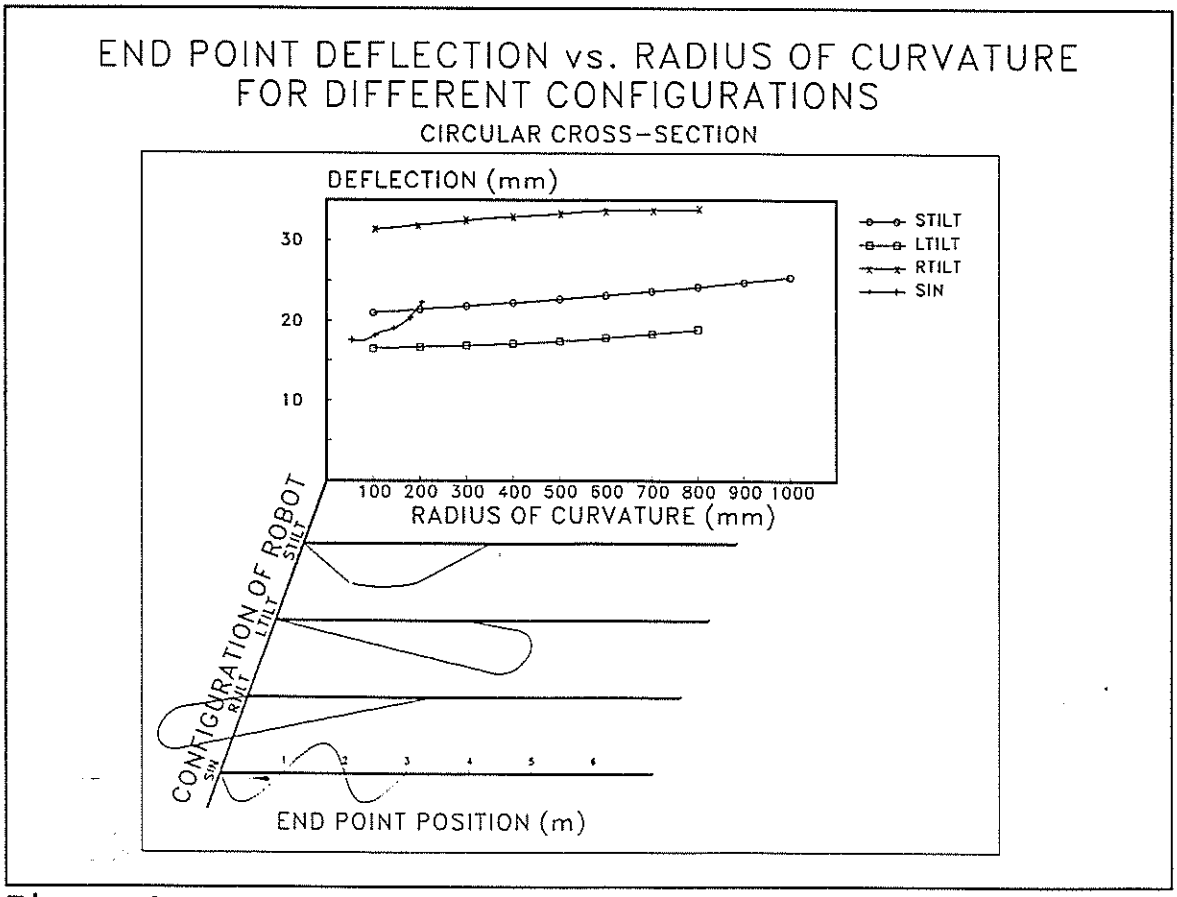


Figure 6

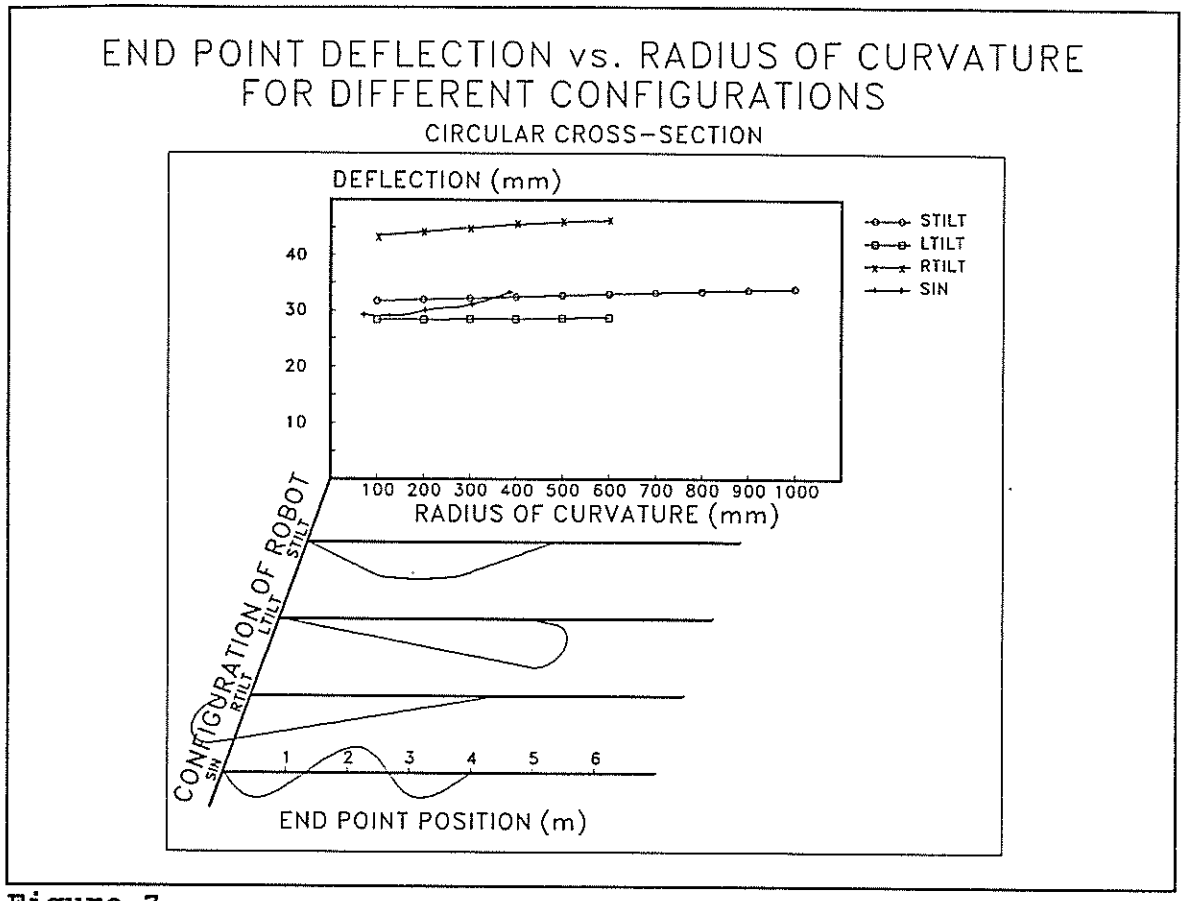


Figure 7

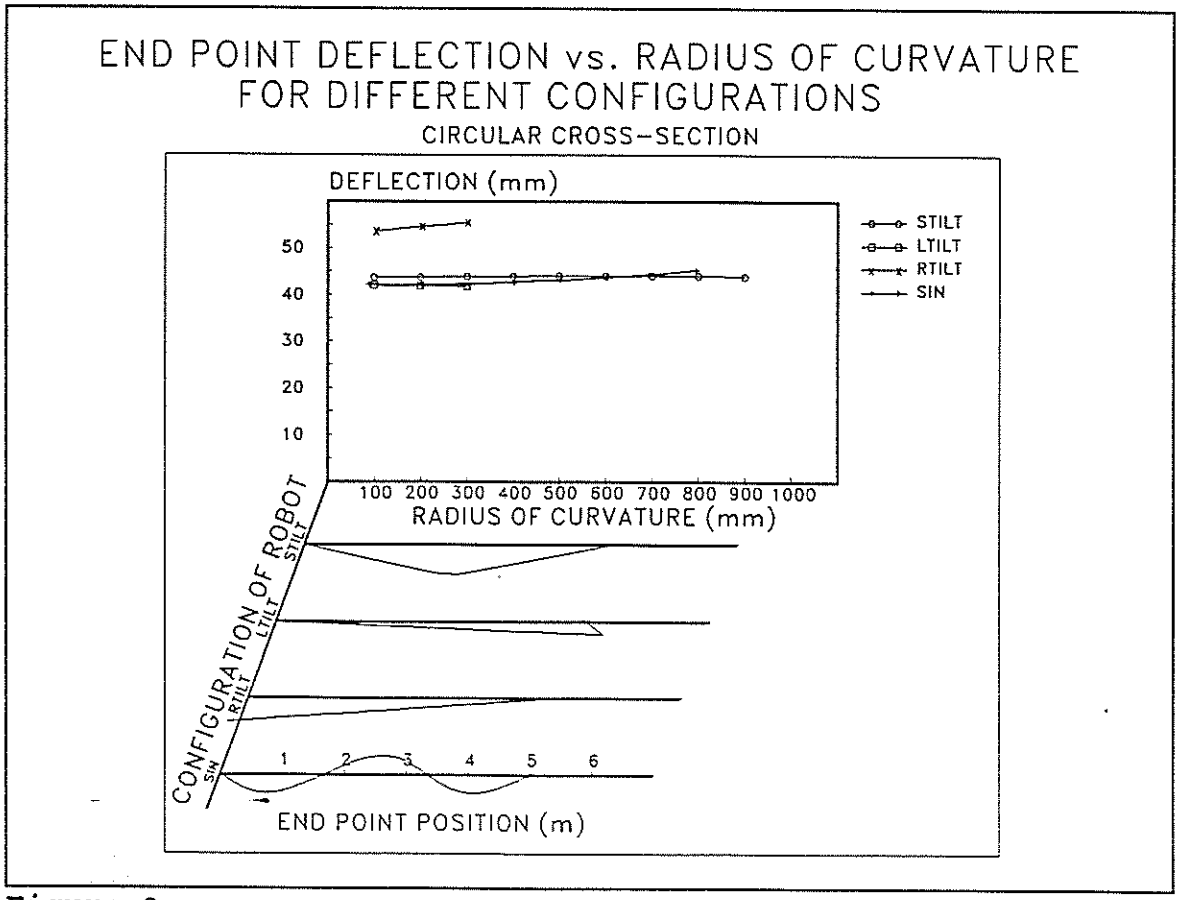


Figure 8

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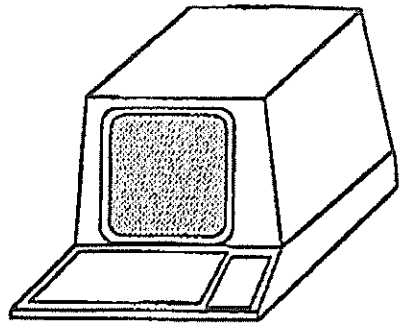
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