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Kinematic Synthesis of Overlay Welding Station Of Elbow

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Abstract: *Overlay welding also known as cladding, is a process in which one or more metals are joined together by welding to the surface of a base metal as a layer in order to improve the corrosion resistance strength of the base metal. in case of conventional type of automatically welding machines, overlay welding of inside surface of elbows cannot be done accurately as there are many areas were the welding torch cannot reach due to curvature effect of the bent section. As a result it became a common practice to perform the welding by hand with the consequent decrease in productivity. The purpose of this paper is to find a solution so that the complete overlay welding of elbow can be done by welding arm itself and thereby increasing the efficiency of the production with no need of manual welding.*
By studying the required motion of the welding torch, physical constraints due to inner overlay in the elbow a feasible solution that can be applied in mass production is obtained. A mechanism was designed according to the motion of the welding torch tip using kinematic synthesis and its development is presented in this paper.
Keywords: *Welding, cladding, Elbo, Kinematic Synthesis*

I. Introduction

Numerous industrial applications require metallic cladding on interior surfaces of metallic pipe with materials to protect against corrosion, abrasion, surface contamination and improved impact resistance. For this purpose, it is preferable to use cladding bends that are of substantially circumferential orientation particularly in applications where the pipe is intended to carry highly abrasive materials such as tar sand slurries. Circumferential application of metallic cladding is relatively simple for straight section of pipe. Helical application is considerably more difficult in the case of curved pipe sections such as pipe elbows.

For the foregoing reasons, there is a need for apparatus for helical deposition of metallic cladding to interior surfaces of curved pipe sections, where the apparatus is readily configurable for use with pipe sections of different diameters, with-out needing to change or replace any components of the apparatus. There is a further need for such apparatus which is readily adaptable for internally cladding curved pipe sections having smaller diameters and curvature radii than can be clad using known apparatus. In addition, there is a need for such apparatus which can internally clad not only the internal surfaces of curved pipe sections but also the internal surfaces of straight transition sections connected there to.

By studying the required motion of the welding torch, a feasible solution can be obtained for physical constraints of overlay operation on the inner surface of elbow that can be applied in mass production. A mechanism can be designed according to the motion of the welding torch tip using kinematic synthesis.

During the overlay welding of inside surface at the curvature section, it was observed that the weld deposition was intermittent at the outer curvature and excess deposition of weld was observed at the inner curvature.

In order to have a uniform and continuous weld surface, the weld torch should perform an oscillating motion with increasing amplitude of oscillation from inner curvature to the outer curvature and in decreasing amplitude of oscillation for the next half revolution. The oscillating motion with varying amplitude can be found to be same as the damping function equation. The constants of the function determines the behavior of motion and the values of these constants and be obtained from the required weld thickness and spread.

The curvilinear motion of the welding torch is necessary for cladding ,in proportion to the radius of curvature of the elbow. To achieve this graphical –dimensional synthesis can be used. Graphical method gives the basic orientation of the links of the proposed mechanism with respect to the required motion, on the other hand dimensional synthesis determines the lengths of the links, necessary to accomplish the desired motion. In order to achieved uniform and continuous weld surface, both the curvilinear motion of welding torch which is concentric with the curvature of elbow and the oscillating motion which is in an direction parallel to the inside surface, should be synchronous.

The purpose of this paper is to find a solution to complete overlay welding of elbow can be done by welding arm itself and thereby increasing the efficiency of the production with no need of manual welding.

II. Literature Review

Manjunath(2007) explained the kinematic modeling of a 5-axis stationary articulated robot arm which is used for doing successful robotic manipulation task in its workspace. A brief kinematic modelling was performed and using this kinematic model, the pick and place task was performed successfully in the work space of the robot. A user friendly GUI was developed in C++ language which was used to perform the successful robotic manipulation task using the developed mathematical kinematic model. This developed kinematic model also incorporates the obstacle avoiding algorithms also during the pick and place operation.

Panich(2015 developed the mathematic model and kinematics of robotic arm. The robotic arm uses the Denavit Hartenberg (D-H) method to determine the parameters with transformation matrices. The direct kinematic analysis was conducted to determine the parameter of robotic arm by using DenavitHartenberg (D-H) method. The calculated parameters of robotic arm were implemented by direct kinematics and compared with the measured parameter by rotary encoder to determine the accuracy of each parameter.

Dutra(2014) shows that it is possible to overcome the technological difficulties for both application sites and to make automatic cladding operations more productive and of a better quality. The proposed cladding technique, which employs simultaneous oscillation of the CNC robot‟s axes, represents a real possibility for improvement of the industrial application of boiler walls cladding. That is provided by the distinctive welding torch trajectory of the CNC robot, which has similar geometric characteristics to the surface of the boiler walls.

Embabo(2014 focus on the problem of industrial robot controlling. He used mechanical theory as guide and makes some mechanical analyses and calculation on the position of end effectors and position of each joint to meet the target off end effectors path. It is important to formulate the suitable kinematics models for a robot mechanisms and it is very crucial for analyzing the behavior of industrial manipulator. This paper analyzes optimum direct and inverse kinematics of an industrial robot.

In addressing the kinematics of welding robot, Dave and Chauhan(2011) discussed simulation of different manipulator for a given value of joint variable and comparing workspace generated by both manipulators. In this work, the analytical model is validated and simulated using Multi-body Dynamics (MBD) of HyperWorks. The objective of paper is to analyze singularities and variation of joint variable for both configurations while moving around a specified path. The link velocity is computed for both configuration and it is compared with analytical model.

It is observed that the developing trajectory for movement of welding arm require a kinematic synthesis. Following this, present work is proposing to develop suitable path generation of welding rod movement for cladding the inner side of elbo.

III. Methodology

In general terms, the present work is an apparatus for applying a circumferentially-oriented metallic cladding bead around the interior surface of a pipe elbow. In the preferred embodiment, the apparatus applies the cladding bead in a helical pattern, but other bead application patterns are possible using alternative embodiments of the apparatus.

Accordingly, in a first aspect the present invention is an apparatus for applying a helical cladding bead to interior surfaces of a circularly curved pipe elbow having a first end, a second end, a curved centerline, a center of curvature, and a plane of curvature, said apparatus comprising: An elbow carriage, a rotor mounted to the elbow carriage and rotatable about a primary axis, Turntable.

Turntable is a mechanical equipment on which fixture for the setup of elbow is done It has a base plate which rotates about y axis and also about x axis It has gear mechanism and servo motor which helps in movement of the base plate. The turntable is classified according to the weight of the component which it can carry. Ex- 1ton , 2 ton etc. The turntable which is used in the setup depends on the weight of the elbow on which the overlay is to be done.

It is a long rod used for welding inside the elbow. It is usually straight or has a bend to facilitate deeper travel of welding rod. The rod is attached to the translator component (horizontal) of the welding machine which helps the motion along x axis. The translator component is also attached to a vertical component which facilitates the movement along y axis.

Offset sensor is placed alongside the elbow. It used to maintain the distance between the sensor and the outer surface of the elbow thereby maintaining the weld arc length of the inner surface of the elbow and the welding tip. In the preferred embodiment, the apparatus comprises means for varying the rotational speed of the rotor during each rotation, to facilitate deposition of weld beads of substantially uniform thickness around the inner perimeter of the elbow. Because of the curvature of the elbow, the width covered by each pass of the weld head will be greater than the pitch (as previously defined) at points on the elbow where the distance to the elbow center of curvature is greater than the elbow‟s radius of curvature (i.e., outboard of the elbow centerline), and less than the pitch at points on the elbow where the distance to the center of curvature is less than the radius of curvature (i.e., inboard of the elbow centerline). The variable- rate rotation means progressively slows the rotation of the rotor as the weld head moves from the most inboard zones of the elbow to the most outboard zones, and correspondingly increases the rotational speed of the rotor as the weld head moves from the most outboard zones toward the most inboard zones. Accordingly, the weld head dwells longer at outboard zones than at inboard zones, thereby facilitating the deposition of a weld bead of substantially uniform thickness around the circumference of the elbow if the wire feed rate to the weld head is kept constant.

The variable-rate rotation mechanism will of necessity be synchronized with the movements of the elbow carriage and the rotation of the weld arm carriage. In alternative embodiments, uniform weld bead thickness may be achieved without varying the rotor"s rate of rotation; by instead varying the wire feed speed. In preferred embodiments, the apparatus is adapted to clad interior surfaces of straight transition sections attached to pipe elbows.

3.1 ACTUAL SETUP

TIG welding machine is easy for arc initiation and has the functions of arc initiation current, arc stop current, welding current, basic value current, current ascending time, current descending time, gas delay time, continuous adjustment. What's more, pulse frequency and pulse duty can also be adjusted independently. It has the characteristics of automatic control of arc initiation, arc stop and stable arc, which make the best result for shape and inner quality of the welding surface. So TIG welding machine WS-315S three Phase is used for the following elbow design.

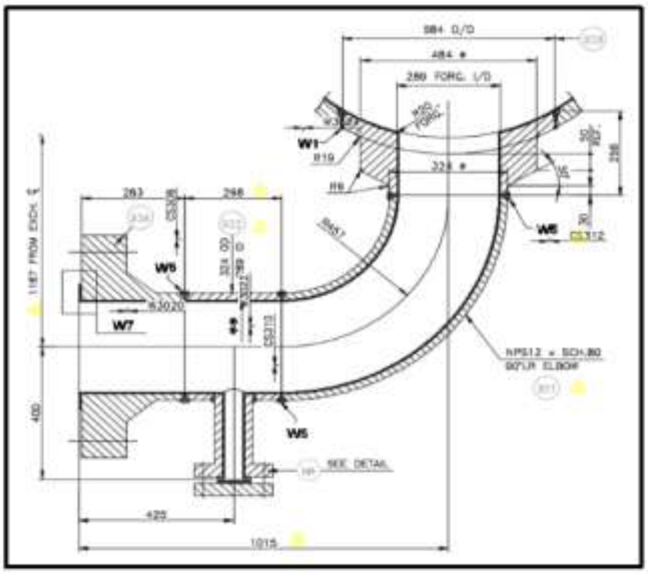

Fig.1 Elbo configuration

For the problem faced by the offset sensor to correct the weld gap between the elbow surface and the electrode, the improvised selection is as follows. The molten metal fallout occurs during the welding operation, the molten metal liquid during welding chops in to the surface of the elbow and forms beads and these beads causes deformities and impurities in the further welding layer deposited. This can be avoided when horizontal axis welding is performed. The welding technique employed is of vertical axis type in which the molten metal drips due to the gravity and this can be avoided by adapting horizontal axis type welding thus by increasing the quality of overlay produced. The other major problem faced was the curvature area difference present between the outside and inner surface and the overlay caused accumulation of metal in the surface of shorter radius and due to the change in curvature it was unable to carry out the overlay operation. This problem is solved by adopting electrode weaving technique. The electrode weaving that should be performed is mainly in the middle portion of the elbow which generally constitutes about a (33% of the total surface area)

3.2 ELBOW OVERLAY STATION WITH FCAW PROCESS

Fig. 2 Elbo overlay station

The process of developing a overlay station is subjected to issues, such as, Molten metal fallout, Curvature and overlay correction, Radial offset sensor correction, Control of angle to produce a semi-automated system or by Ratchet mechanism ,Adding/Incorporating an extra degree.

3.3 MOLTEN METAL FALLOUT

Molten metal fallout is undesirable phenomenon that happens in overlay welding. This happens usually when the weld position is vertical or overhead welding. Welding is basically melting the parent metal and the metal to be joined thereby creating a molten pool and fused both the metal in the pool thereby join them. During vertical and overhead welding when the welding pool is formed, it does not solidify as fast as required which leads to dripping of molten pool downward or in toward the direction of gravity In the current setup in, the position of welding used is vertical welding. The process goes such that one circular path is followed thereby overlay of one layer is done than setup is moved down to second layer below it. Now during the process, the molten pool formed during overlay does not solidify as early as expected thereby dripping and giving a bad finish to the layer. This also proves a hindrance to the path of the second layer that has to be done. Adjust the setup such that the position of the weld is down hand position. By adjusting the position in such a way that, the fallout happening due to gravity will be automatically cancelled out. For creating the down hand position the turntable which controls the movement of the elbow will have to rotate to a whole 90^0.When the turntable is rotated to 90^0 the path of the elbow on which overlay welding has to be done will be parallel to the ground. The welding rod will also have to adjusted in such a way that it penetrates deeply into the elbow.

3.4 CORRECTION IN RADIAL OFFSET SENSOR

It is very difficult to rotate the turntable to 90^0 because it changes the Centre of gravity drastically makes it difficult to balance the setup and elbow. There are errors generated in the radial offset sensor due to the curvature of the elbow due to which there is a variation in the distance measured this can be corrected by incorporating the angle by which the link is moved the resulting equation for the corrected length which is to be compared with a fixed value for obtaining the required length of stick out (weld gap) to produce a more effective weld deposition or else it would result in spatter of the weld metal resulting in to formation of weld defects.

$$y = l - [(l_1 + d)Cos\theta_1 + l_2 Sin\theta_2]$$

Where,

y - the measured distance,

l - distance between the probes of the sensor,

l_1, l_2 – length of the shorter and longer links respectively,

θ_1, θ_2 -angular rotation given to the links respectively,

d- distance of the weld gap.

To produce semi-automated system the use of various sensor for sensing the parameters is crucial. To make the given system an automated systems the sensing and control of the angular rotation of various links is necessary this can be achieved by placing a series of limit switches around the mounted end of the longer link and a greater control can be achieved and the need of specialized sensor for the welding environment is avoided. The limit switches can be controlled to keep a track of angle rotated and can be easily controlled.

3.5 THE MECHANISM OF THE POSITIONER

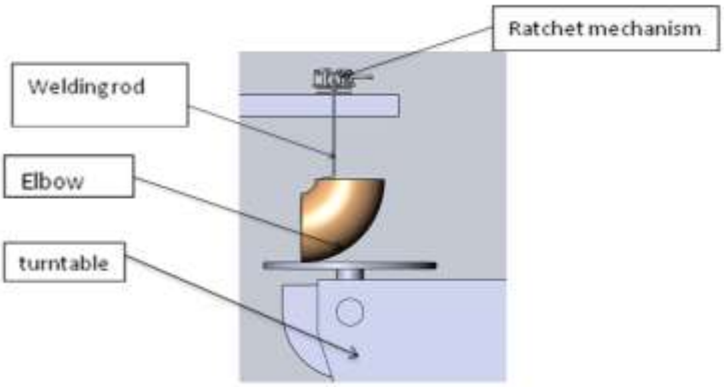

Fig 3 Setup Using Ratchet Mechanism

Initially the welding elbow is clamped to the turntable (not shown for simplicity) and the welding rod tip is adjusted normal to the welding surface from inside of the elbow as shown above. The turntable is then started with the help of an AC induction motor such that the table rotates along the axis of welding rod such that the welding rod is parallel to the axis of rotation of the table. For every complete rotation of the turntable, the welding rod moves 1step downward vertically about a distance equal to the weld width (y). The sequential motion is achieved with the help of the limit switch attached to the turntable. Also after every rotation of the turntable, it is rotated equal to ‘ Θ_t ‘ value which in turn depends upon the geometry of the elbow. Simultaneously the welding rod is also tilted or rotated manually with the help of ratchet mechanism provided as shown above. The welding rod is clipped to the ratchet. The tilting axis is perpendicular to the axis of rotation as show above. In this way the sequence is repeated for every rotation of the turntable. The entire motion of the sytem has to be stop when the axis of rotation makes an angle of 45^o (maximum) with the ground (to prevent falling off due to its own weight).

In this way the first stage of the operation is completed. the another half of the elbow is welded by following similar steps after reversing the configuration of the elbow clamped on the turntable. the ratchet mechanism used to tilt the welding rod is explained below.

3.6 THE RATCHET MECHANISM

The ratchet mechanism or system consist of standard ratchet and pawls , stands for ratchet and pawl, and handle to rotate the ratchet by moving the spring operated pawls show above. Springs are used to keep the pawls horizontal or parallel to the ground (in order to help in engagement and disengagement properly) The specifications of the ratchet and pawls are:

a. Pawls limit direction of spin to one direction; has induction hardened tips for superior durability.
b. ratchet having standard specifications as:-

Pitch: 3.14 mm/tooth
Outside Diameter: 3.94in
Teeth: 100
Bore Diameter: 0.591in

Whenever the elbow i.e., the turntable is titled the welding rod also rotated by rotating the ratchet which is rotated with the help of a pawl attached to the handle as show above. when the handle is moved upward the pawl moves forward and pushes the teeth on the ratchet so that the ratchet start rotating(counter clockwise) . In order to prevent the backward motion (clockwise rotation) due to the weight of the welding an extra pawl(stopping pawl) is used in order to lock the ratchet at that particular location after every forward motion of the rotating pawl. In this way after every one teeth displacement of the ratchet it is locked in that position and the angle made by the welding arm tip with the axis of elbow always remains normal(which is required for good welding action).

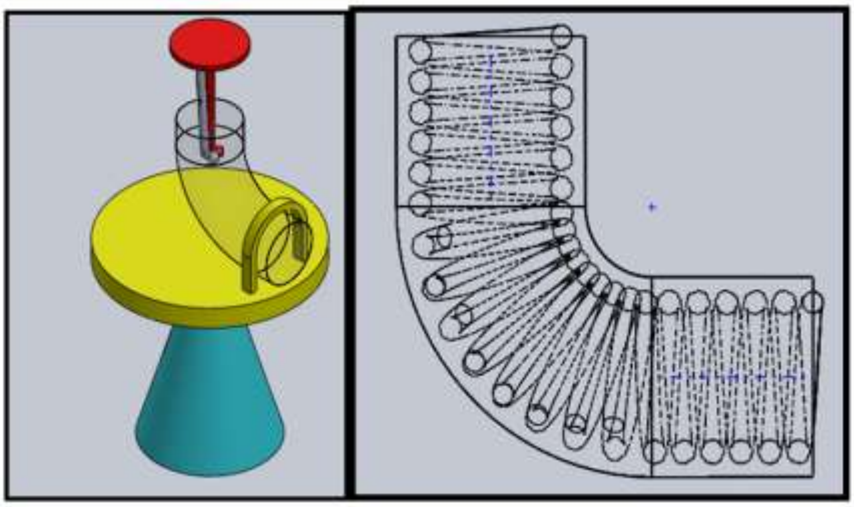

Fig 4 General orientation of overlay station

The Sinusoidal weaving is achieved using following equation.

$$\frac{\{f(b)\cos(f(w))+2f(b)\sin(f(w))\}*\pi}{\sqrt{x}}$$

The above mentioned equation yields the graph shown and is obtained by trial and error method and is bounded with an defined range depending on the value of ‘b’

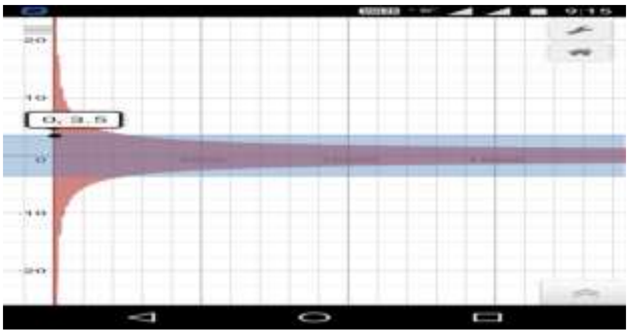

Fig 5 Output of sinusoidal weaving process

In sinusoidal weaving pattern the major concern found is that there is not enough time available for the weld to cool before the torch approaches the region again due to distortion occurs and large thermal stresses are generated in the elbow pipe. Linear weaving approach overcomes this and the time period is found comparatively large.

In this technique we would focus on performing patching y filling the gaps formed by circumferential weld. And the circumferential weld lengths are controlled by the gap.

IV. Validation

The virtual model is required to create and implement the concept. The mathematical model provides the basis for synthesizing the dimensions of the various bodies and parts to be assembled. the virtual model of the work station is created in solidworks and analyzed. The mathematical model is created and generated model is analyzed in the MATLAB simulink. The angular variation is studied using the inverse kinematic analysis and plotted in the graph.

The model built in the Matlab simulink without taking in to account the transverse displacement parameter and the model generated is as shown in the fig below.

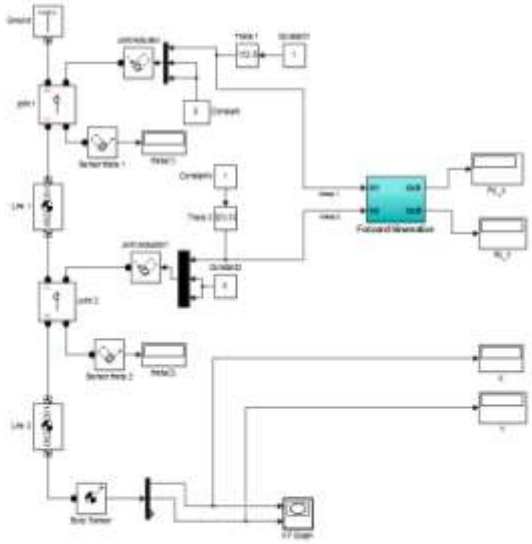

Fig 6 Simulink Model

The outputs of the analysis are shown in the following fig.

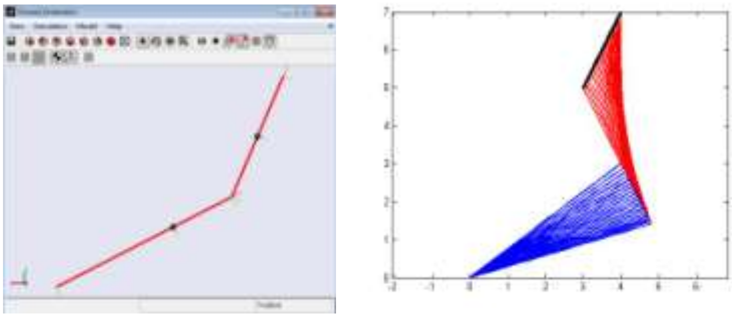

Fig 7 Simulink iteration and Model

The angular variation are plotted in the links by using the inverse kinematic analysis of the links. The Theoretical model i.e. mathematical model is to be checked with some CAD modeling for feasibility. The kinematic and dynamic equations can provide strong basis for design of joints and numerical values can be obtained to select the actuators to drive the joints. However, it is necessary to prepare 3D CAD model and carryout Kinematic and Dynamic analysis to validate mathematical model.

The methodology can be extended to analyze various manipulators for the same inputs and mathematical modeling and programming is required to facilitate solution for all type of configurations. Further analysis can be carried out by building the model and converting it into .step file and by importing it in Multi Body Dynamics (MBD) environment MotionView of HyperWorks to carryout kinematic and dynamic analysis. The software solution will enable the learner to develop the concept from basic mathematics to actual prototype development to achieve objectives.

V. Conclusion

This paper does not include the effect of varying welding parameters such as weld residual stresses, contact tip to work distance(CTWD) etc. of inside surface overlay welding of elbow. It deals only with the kinematical motion study of mechanism for a particular application. Further investigation is needed to determine the effect of varying welding parameters on the dimensions of the links of the mechanism.

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