Design and Analysis of driving mechanism for semi-automatic welding machine.

Kalyan Inamdar, Rohit Suryawanshi, Monica Patil, Sanchit Ingale, Nikhil Wagh

Abstract:
The project comprises of design modelling and analysis of driving mechanism for semi automatic welding assembly used to weld canisters of 2 to 2.5m diameter. The aim is to design a motion transfer mechanism for the welding arm to facilitate longitudinal and circumferential welding of canisters. The quality of welding is being affected by current system in operation due to vibrations induced by various parameters.

Index terms: ANSYS V14.5, CATIA V5R21, Chain and Sprocket, Rack and Pinion, Welding Assembly

1. Introduction:
The welding machine in the Fabrication Department is used for circumferential and longitudinal welding of large canisters that are used in various industrial sectors. The integrity of canisters relies on the quality of weld joint. The welding of is done by CO2 gas welding. The welding assembly in the department is currently not functional, so it is done by the workers by hand. Due to large diameters, they have to climb up the canisters and have to weld with their one hand while maintaining their balance. This deteriorates the weld quality and increases their effort.

2. Problem statement:
To design a semi-automatic driving mechanism for welding assembly used for welding large diameter canisters used in pumps and to minimize the vibration in the system while improving the stability.

3. Objective:
1. Identifying the primary causes of weld quality deterioration.
2. Making necessary modification in the system to minimise these factor and designing a replacement if necessary.
3. Validating the design by analysis of computer model of actual dimensions.

4. Possible solution after extensive study:
After studying the current assembly we came up with the following solutions for the driving mechanism.

4.1 Lead screw with recirculating balls.
A ball screw is a mechanical linear actuator that translates rotational motion to linear motion with little friction.

4.2 Hydraulic system:
Hydraulic drive system is a drive or transmission system that uses pressurised hydraulic fuel to drive hydraulic machinery.
4.3 Rack and pinion:

It is a type of linear actuator that comprises of a pair of gears which converts rotational motion into linear motion. A circular gear called pinion engages teeth on a linear gear bar called the rack.

5. Comparison:

5.1 Lead screw with recirculating balls:

Advantages:
- Extremely smooth
- High efficiency with reduced power requirement

Disadvantage:
- Very high cost.
- Can be back driven due to low internal friction.

5.2 Rack and pinion:

Advantages:
- Very smooth and efficient power transmission.
- No noise. (in helical)
- Moderate cost
- Low maintenance

Disadvantage:
- Complicated design.

5.3 Hydraulic system:

Advantages:
- Smooth and noiseless operation.
- Easy control of whole system.

6. Literature Outcome:

Comparing the pros and cons of the above four alternatives, we decide to design the rack and pinion driving mechanism due to its following advantages over the rest:

1. Smoother Motion Transfer
2. Low Maintenance
3. Comparatively low cost
4. Less modifications in the current assembly
5. No noise

7. Methodology:

1. From literature outcome we inferred that the most suitable assembly for the driving mechanism would be helical rack and pinion.
2. Then we took measurements of the space constraints and referred cost charts for the standard materials used for gears.
3. Next step was to select suitable gear materials by cost comparison and considering the space limitations.
4. After that we designed the system for the dimension limitations with the selected material and selected higher grade material if required.
5. The dimensions obtained were then used to prepare a computer model in ANSYS for further validation.
6. The last step consisted of reading and interpreting the results in the form of plots and tables to validate the design.
8. The welding assembly[1]

8.1 Assembly and its components:

The current assembly in the company as shown in figure has following main components:

1. Frame:
   It is a two legged frame which has motor and gear box mounted on it with a horizontal track for driving mechanism. It also has a lateral extension with facility for vertical and horizontal arrangements to change the length of the arm which mounts the welding arm.

2. Lateral arm:
   It is an extension on the driven part to facilitate the welding of large diameter canister. It has arrangements for changing the horizontal and vertical length. It also has the mounting necessary to mount the welding torch.

3. Motor:
   The motor is used to drive the arm in horizontal direction. The speed is reduced through a worm reducer gear box to the required extent. The specifications are:
   Motor:
   Make: Crompton Greaves
   Rating: 0.75 kW for 415 V, 1.81 A (3-phase), 50Hz
   Speed: 1410 RPM
   Efficiency: 78%

4. Speed and direction controller:
   It is an electrical controller accessible to the operator. It controls the direction of movement of the arm as well as its speed.
5. Gear Box:
   Make: Radicon
   Type: Worm reducer (A 2-37)
   Reduction Ratio: 60:1

6. Transformer and Welding Torch:
   The welding torch is mounted to the arm and the transformer is kept on the moving platform besides the motor and gear box assembly.

7. Bearing:
   The bearing provide smooth motion for the platform hosting the motor, gear box and the transformer. All the load is ultimately taken by its bearing. There are total 12 roller wheel bearings on the assembly.

9. Design of the Welding Assembly:

   **Nomenclature:**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>η</td>
<td>Efficiency</td>
</tr>
<tr>
<td>G</td>
<td>Gear Ratio</td>
</tr>
<tr>
<td>Sₜₜ</td>
<td>Ultimate Tensile Strength</td>
</tr>
<tr>
<td>BHN</td>
<td>Brinell Hardness Number</td>
</tr>
<tr>
<td>β</td>
<td>Helix angle</td>
</tr>
<tr>
<td>Zₘᵢₙ</td>
<td>Minimum no. of teeth to avoid interference</td>
</tr>
<tr>
<td>Σₛₜ</td>
<td>Allowable Bending Stress</td>
</tr>
<tr>
<td>Y</td>
<td>Lewis Form Factor</td>
</tr>
<tr>
<td>Mₑ</td>
<td>Normal Module</td>
</tr>
<tr>
<td>Mₜ</td>
<td>Transverse Module</td>
</tr>
<tr>
<td>R₀</td>
<td>Pitch Circle Radius</td>
</tr>
<tr>
<td>Rᵣ</td>
<td>Base Circle Radius</td>
</tr>
<tr>
<td>R₀ₜ</td>
<td>Dedendum Circle Radius</td>
</tr>
<tr>
<td>Rₜₜ</td>
<td>Addendum Circle Radius</td>
</tr>
<tr>
<td>Xₑ</td>
<td>Normal Profile Shift Coefficient</td>
</tr>
</tbody>
</table>

The first thing to be considered while designing any system of gears is the input
power provided by the prime mover will be sufficient enough to carry out the operation to be done and how much is the output power required. The assembly at the company is driven by an electrical motor with the rating, 0.75 kW at 1410 RPM, through a worm reducer gearbox with 60:1 reduction ratio. Therefore, the output speed from the gearbox can be calculated by the formula procedure.

\[ G = \frac{Zg}{\text{No. of starts}} = \frac{Np}{Ng} \]

\[ G = \frac{60}{1} = 1410 / N_g \]

\[ N_g = \frac{1410}{60} = 23.5 \text{ RPM.} \]

The output power and essentially the torque available from the gearbox must be sufficient to be able to drive assembly. The efficiency of the motor is 78%. The efficiency of the reduction gearbox lies between 88% and 94%. Hence, assuming the efficiency of the gearbox to be 90%, the output power can now be calculated as,

Output power = (Input power * efficiency of the motor * efficiency of the gearbox)

Output power = 0.75*10^3*0.78*0.75 = 526.5 W = 0.5625kW.

The power is given by,

\[ P = \frac{(2 \pi N T)}{60} \text{ W.} \]

The torque can be calculated by,

\[ T = \frac{(P \times 60)}{(2 \pi N)} \text{ Nm} \]

\[ T = \frac{(0.5265 \times 10^3 \times 60)}{(2 \pi \times 23.5)} = 213.94 \text{ Nm} \]

Thus, it is also concluded that the torque output from the gearbox is sufficient to move the assembly.

8.1 Design Procedure

Motor Rating:

\[ P=0.75kW \]

\[ N=1410 \text{rpm} \]

\[ \eta=78\% \]

Gearbox Rating

\[ G=60:1 \]

\[ \eta=90\% \]

Input \[ \rightarrow \] Motor \[ \rightarrow \] Gearbox \[ \rightarrow \] Output

\[ P_i=0.585kw \]

\[ P_o=\eta P = 0.5265kw \]

Speed

\[ G = \frac{N_{motor}}{N_{pinion}} \]

\[ N_p=23.5 \text{ rpm} \]

Selecting 40C8 as the material for gears since it is the cheapest material meeting the stress requirements,
40C8

\( S_{sw} = 580 \text{ MPa} \)
\( BHN = 460 \) (case hardened)
\( \beta = 19.528^\circ \) \( Z_{min} = 18 \quad \text{FOS} = 1.5 \)
\( \sigma_p = 193.33 \text{ MPa} \)
\( Z_p = Z_p(\cos^2\beta) = 21.501 \)
\( \gamma = 0.484 - 2.87/Z = 0.3505 \)

**Bending**
\( F_b = \sigma_p b m \gamma \)
\( b = 1.15 \pi m / \sin \beta = 10.808 \text{ m} \)
\( F_b = 732.16 \text{ m}^2 \)

**Wear**
\( D_p = m s_2 \cos \beta = 19.098 \text{ m} \)
\( P - \pi d s / Z \)
\( Z_p = l / p = 3280 / 3.333 = 984.09 / \text{m} \)
\( Q = 2, Z_p + Z = 1968 / 984.09 + 18 \text{ m} \)
\( K = 0.16(4.6)^2 = 3.3856 \)
\( F_w = d_p B Q K / \cos^2 \beta \)
\( = 154833.738 \text{ m}^2 \)/ (984.09 + 18 m)

For \( m = 1 \)
\( F_w = 1545.204 \text{ N} \)
\( F_b = 732.16 \text{ N} \)

For \( m = 10 \)
\( F_w = 133016.668 \text{ N} \)
\( F_b = 73216 \text{ N} \)

It is seen that
\( F_b < F_w \)

Hence we design the gear pair considering the bending failure.

**Effective Load:**
\( V = \pi d_p n / 6 \times 10^3 = 0.0235 \text{ m} \)
\( F_e = P / V = 22404.2553 / \text{ m} \)
\( K_v = 5.6/ (5.6 + V^{1/2}) = 5.6/(5.6 + 0.1533m^{1/2}) \)

\( F_{eff} = k_v k_m F_b / k_v \)
\( K_v = 1.25 \quad K_m = 1.3 \)
\( F_{eff} = 6501.23 (5.6 + 0.1533m^{1/2}) / \text{ m} \)
\( F_e = N_f * F_{eff} \)
\( M_t = 4.2875 \)
\( M_m = 4.5 \)

Hence the final dimensions are:
\( M_t = 5 \text{ m} \)
\( M_m = 5.05 \text{ mm} \)
\( D_p = 95.5 \text{ mm} \)
\( Z_p = 18 \)
Outer diameter of pinion = 103.5 mm

Rack length = 3.28 m
Pinion hub diameter = 25 mm

Since these dimensions are greater than the space constraints, we chose higher grade material.

55C8:
\( \sigma = 240 \text{ MPa} \)
\( BHN = 520 \)
\( Z_p = Z_p(\cos^2\beta) = 21.501 \)
\( \gamma = 0.484 - 2.87/Z = 0.3505 \)

**Bending:**
\( F_b = \sigma_p b m \gamma \)
\( F_b = 908.909 \text{ m}^2 \)
\( K = 4.3264 \)

**Wear:**
\( F_w = d_p B Q K / \cos^2 \beta = 1978716.836 / (984.09 + 18 m) \)

For \( m = 1 \)
\( F_w = 1974.59 \text{ N} \)
\( F_b = 908.909 \text{ N} \)

For \( m = 10 \)
\( F_w = 175404.164 \text{ N} \)
\( F_b = 90990.9 \text{ N} \)
Comparing the two values

\[ F_b < F_w \]

Hence the gear pair is designed considering bending failure.

**Effective Load:**

\[ V = \pi d_p n_p / 6 \times 10^3 = 0.0235 \text{ m} \]

\[ F_e = P / V = 22404.253 / \text{ m} \]

\[ K_v = 5.6 / (5.6 + V^{1/2}) = 5.6 / (5.6 + 0.1533 \text{ m}^{1/2}) \]

**Final Dimensions:**

\[ M_n = 4 \text{ mm} \quad m = 4.244 \text{ mm} \]

\[ D_p = 76.4 \text{ mm} \]

\[ Z_p = 18 \]

Outer diameter of pinion = 84.4 mm

Rack length = 3.28 m

Pinion hub diameter = 25 mm

**Mounting Distance:**

\[ = Z_m/2 \cos \beta + H + x_m \]

\[ X_m = \text{normal profile shift coefficient} = 0 \]

\[ H = \text{dedendum} + \text{width of base} \]

\[ = 5 + 15 \]

\[ = 20 \text{ mm} \]

Mounting distance = 58.197 mm

9. Finite element analysis of the welding assembly:

The finite element method is the technique for obtaining approximate numerical solution to boundary value problems to predict the response of physical systems subjected to external loads. In general FEA begins by generating FE model of a system. In this method, the subject structure is reduced into a number of load points that are connected together to form finite elements. The governing equation of the motion are written in discrete forms, where displacement of each node is the unknown part of the solution. A simulation load or other external influence is applied to a system and resulting effect is analyzed.

9.1 Different software packages used for simulation:

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Software package</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>CATIA V5R21</td>
<td>For 3D modelling of tilting table</td>
</tr>
<tr>
<td>2.</td>
<td>ANSYS 14.5</td>
<td>Meshing, Loading, constraining, solving and post processing.</td>
</tr>
</tbody>
</table>

9.2 3D models

The entire welding assembly with chain-sprocket and rack-pinion was modelled and drafted in CATIA V5 R21.
9.3 Meshing of the assembly

The models were then imported to ANSYS 14.5 for further analysis. Meshing was done on the total assembly and fine meshing was done at the critical areas where the maximum stresses are expected. The quality of mesh was maintained by following the standard quality criteria like aspect ratio less than 5, jacobian ratio in between 0.7 to 10, warpage less than 15 and minimum angle of quad 45, maximum angle 135. Continuity between all the elements was maintained.

10. Post-processing:

Post processing was done using ANSYS V14.5 in order to determine the equivalent (Von Mises) stress. The analysis with indexing is shown in the figures below.
It is observed from the Structural Diagram that the Maximum Principal Stress for Chain and Sprocket assembly (FIG A) is 1125.3 MPa and Equivalent (Von Mises) Stress (FIG B) is 1273 MPa.

The Maximum Principal Stress (FIG D) for Rack and Pinion assembly is 42.912 MPa and Equivalent (Von Mises) Stress (FIG C) is 63.596 MPa.

11. Conclusion:

The welding assembly was designed as per the requirement of WILO’s Mather Platt Pumps Ltd. The new model consists of modified driving mechanism with improved motion transfer and more smoothness in motion. The conclusion drawn from the two models on which analysis were performed are as follows:

- The stresses induced in the rack and pinion are much less than the stresses induced in chain and sprocket which tend to bend the sprocket. The chain and the sprocket is not strong enough to handle the power and torque supplied by the motor through gear box.
- The quality of circumferential and longitudinal welding can be improved when the system is modified as per the solutions discussed above.
- By implementing the above solutions for secondary parameters, the vibrations can be reduced to a desired level and the canisters can be welded ensuring the desired weld quality.

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References:

[1] WILO’s Mather Platt Ltd.
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