REDUCING VIBRATION LEVEL FOR THE CONVEYOR DRIVE CHAIN EQUIPMENTS: DESIGN ASPECTS & INSTALLATION INSTRUCTIONS

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Abstract

Vibration level is a critical parameter of any rotating equipment in bulk material handling system. Most of the specifications bind the vibration level as an acceptance standard for the system in the guarantee test proforma/ Performance Guarantee test protocol. Generally VDI 2056 is used as the criteria for assessing the mechanical vibrations of machines. The value of vibration level for any rotodynamic equipment is a manifestation of the bearing status, alignment with the drive chain equipments or system, vibrations conveyed by the driving/driven equipments. Prolonged vibration and high value of amplitude can result in repeated stresses and even falls out to supporting member failure at stresses before yield point stresses by means of progressive crack formation which are usually fine and microscopic in nature. Critical supporting structures should be analyzed (modal analysis of Finite element package) to ensure that the natural frequency of the supporting structure is greater than the applied frequency of the vibrating machinery or the belt in order to avoid resonance. In this article, the focus is on the methods (design principles as well as the guidelines to be followed during installation) to control vibrations of drive chain equipments-motor, fluid coupling and gearbox- of a conveyor used in raw material handling system.

Key-words: Vibration level, Conveyor, Conveyor drive, motor, fluid coupling, gearbox, geared coupling, GD² value, moment of inertia, AGMA standard, CEMA standard

INTRODUCTION

Conventionally the drive of a belt conveyor consists of a motor (squirrel cage induction type), fluid coupling (traction type or delayed fill chamber type for LT drives and scoop type for HT drive) and gearbox connected to the drive pulley. The drive chain equipments are mounted on drive base frames which are fabricated structures and are fixed either on structural stools or RCC foundations on the transfer point floors. The structural designer should not only take care of the dead loads of equipments but also should consider the movements, torques and moments induced by moving parts. There should be proper co-ordination between the structural designer and the equipment supplier in order to match the base plate locations, anchor bolt hole locations, clearance requirements, static and dynamic load considerations.

When the conveyor is under operation, the vibrations of drive can shoot up to a deplorable value due to a range of reasons. Under-rated drive chain equipments, imbalance in the rotating mass of the equipments, misalignment between the motor- coupling- gear box-pulley, under-designed drive base frame, lack of proper slenderness and stiffness of the supporting beams and tie members of the floor, excessive backlash and undercutting of teeth in gearbox, abnormality in the oil level in fluid coupling,
improper foundation bolt tightening, belt transverse vibrations (belt flap), extreme impact of the feeding material (for belt feeders and small conveyors) etc are few of the causes. A considerable amount of catastrophe can be avoided by taking care of critical causes of vibration during design stage.

Case study was performed for a 1600mm Belt Width conveyor with a belt speed of 2.8m/s carrying material at a flow rate of 1400 tons per hour. There are different patterns of vibration in the drive system which are dependent on the length of the conveyor, drive rating etc. A belt conveyor being a dynamic mechanical system, with the potential for acceleration, always has high value of vibrations at the starting. The crux of the study is that manufacturers catalogues, instructions for installation, operations and maintenance manuals, general arrangement drawings and datasheets should be carefully studied by the construction engineer before taking up the erection. Proper storage and preservation at site is also a pre-requisite to curb vibration as similar to the case of ensuring a healthy and long lasting performance.

**DESIGN FUNDAMENTALS FOR THE DRIVE CHAIN EQUIPMENTS & DRIVE BASE FRAMES TO REDUCE VIBRATION**

The selection of motor coupling gearbox starts with the motor power calculation based on CEMA 6th edition or IS:11592 standard. Various resistances to the conveyor movement are worked out based on the empirical relationships, graphs and basic laws of mechanics which on summation gives the peripheral force required at the drive pulley often referred as the effective tension. The effective tension multiplied by the belt velocity gives the shaft power over which margin is considered to select the motor rating.

The fluid coupling (high-speed coupling) is selected based on the motor kW vs RPM of the motor curve which is often shown in the “selection procedure” of equipment manufacturer’s catalogue. A very critical parameter to be cross checked in order to curb the performance aberrations (which include excessive sound and vibration) is to superimpose the characteristic curves (torque speed curve for various percentages of the machine speed and motor speed) of the fluid coupling to that of the motor. While selecting the frame size of the motor, the designer has to consider the GD² value (mass moment of inertia in gravitational units) of the fluid coupling at the impeller side and runner side. HT as well as LT motors, till they reach their no load speed draws heavy current. The time required to reach the no load speed depends on the inertia of the rotor and inertia of the primary side of the coupling, which is directly connected to the motor. An erroneous estimation of this time (a case where the data of primary side moment or inertia is missing) will lead to working out of a wrong value of the current drawn during the no load period and physically, during operation, can lead to excessive heating of motor. This one to one relationship between the speeding up of the motor and GD² value is often overlooked during the design stage and result is a conveyor which is “good” during steady running, but not running “satisfactorily” at starting and stopping stage.

Fluid coupling is a power transmission equipment with the elements at primary and secondary side made of light density material (preferably of cast aluminium alloys). In-process inspection should be carried out by the equipment manufacturer for the balancing of impeller, runner, casing and chamber to
detect the residual unbalance; Gr 6.3 of ISO 1940 part I is a reliable acceptance norm in this regard. In the free running test during final inspection, the coupling should be spinned at its rated rpm for a duration of around 30 minutes and vibrations shall be measured at horizontal, axial and radial positions. Generally the acceptance value is around 7.1mm/s rms speed in velocity mode for fluid couplings.

The reducer used in a conveyor drive is selected based on 5 parameters:

- Minimum required mechanical rating
- Minimum required thermal rating (maximum power that can be transmitted by the gearbox while not exceeding the sump temperature)
- Speed ratio
- Type of handing
- Method of cooling

Proper selection of gear drive also needs a thorough cross check with the axial thrust (which is a small value in conveyor drives), over-hung load, bending moment, environment and facility needs. In a designer’s perspective, the vibration is a function of the tangential tooth load (accounted in the service factor to work out mechanical capacity), thermal stresses, method of cooling, internal mass distribution of the shafts and meshing gears. Gearboxes rated according to AGMA invariably should be designed considering load dependent power losses like bearing power loss, gear mess power loss and no load power loss including internal windage losses, oil seal losses and oil churning losses.

Bearing performance typically has an impact on the magnitude of vibration. Typically two stage reduction gearbox will have a taper roller bearings mounted on input shaft and spherical roller bearings on output shaft and a combination of taper roller bearings and parallel roller bearing for idle shaft. A system designer should remember that high L-10 life can have adverse effects on performance especially in light loads which cause rollers to skid. Caution should be used while standardizing the small size gearbox sizes for multiple conveyor applications (like that of belt feeders and shuttle conveyors) especially in applications of taper roller bearings and spherical roller bearings as for a given bearing friction torque and bearing shaft speed, the power losses are maximum for taper roller and spherical roller bearings.

The specifications of major consultants and owner’s engineers stipulate to use geared coupling on the output side (slow speed side) of a gearbox to couple with the pulley. The crowning of teeth is a pre-requisite for regulating the parallel and angular mis-alignment, thereby reducing the level of vibration. Of utmost importance is the proper internal gear meshing between the sleeve and hub of the gear coupling. Because the geared coupling is used in the high torque side of the conveyor system, it is important that material selected for the sleeve and hub have sufficient yield strength. There are cases reported in which hair line cracks appear on the gear coupling sleeves as a result of the vibrations. Typically material equivalent or superior to EN-8 (conforming to BS:970)/ 45C8 for hub and cast steel for sleeve is rigid enough to sustain the normal operational loads.

The drive end structure/ drive base frame shall be made sufficiently rigid to prevent any vibration and shall be provided with sufficient maintenance platform all around. For vibration analysis, most of the
finite element packages begin with a mode shape analysis based on the stiffness and the resulting deflections. The member selection of the drive base frame depends on a variety of combination of loads like dead and live loads of motor, couplings, brakes (if applicable) and gearboxes. As observed in many of the cases, higher distance of the centerline of drive pulley shaft from the floor calls for heavier design of the drive base frame. The drive base frames with longer footings often require more tie-members in order to ensure the ability of frame to share the load uniformly on to individual members. The base plate locations of the drive equipments should be supported on to sufficiently rigid members. In case rolled sections are used, sufficient stiffners shall be provided beneath the base plate location. For drives of rating 45 to 110 kW, ISMB 200 members shall be used for equipment mounting. For rating range of 110 to 180 kW, minimum section to be used is ISMB 250. For drive rating of 180kW to 260 kW, the minimum section to be used is ISMB 300. In the motor power range of 260 to 500kW, the minimum section to be used is ISMB350. The level of vibrations is a function of the supporting arrangement for the drive base frame- which is either by using fabricated stools or by RCC pedestals. The use of stools is a common practice these days as it has an advantage of directly transferring the load to the floor beams and hence to the building columns. The probable crack generation and propagation of RCC floor is also avoided in the case of fixing over stools.

Belt flap is a complex issue encountered in conveyors (especially in reversible yard conveyors) resulting in dynamic transverse vibration in belt and drive pulley. In the design phase the spacing between idlers should be suitably selected considering the vertical drop between idlers, idler roll diameters and the belt speed.

**INSTALLATION INSTRUCTIONS TO REDUCE THE VIBRATION LEVEL**

- The drive alignment of a conveyor system is the most “precision task” in the installation process. The equipment manufacturer typically sets the alignment tolerances. However in case the data is not available, table 1.0 can be used.

<table>
<thead>
<tr>
<th>SL NO</th>
<th>ITEM DESCRIPTION</th>
<th>ACCEPTABLE RADIAL TOLERANCE</th>
<th>AXIAL TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motor</td>
<td>±0.05 mm</td>
<td>±0.05 mm</td>
</tr>
<tr>
<td>2</td>
<td>Scoop type fluid coupling</td>
<td>±0.1mm</td>
<td>±0.1 mm</td>
</tr>
<tr>
<td>3</td>
<td>Gearbox</td>
<td>±0.05 mm ( for shaft diameter upto 150mm) and ±0.1mm (for shaft diameters above 150mm)</td>
<td>±0.1 mm</td>
</tr>
<tr>
<td>4</td>
<td>Gear coupling</td>
<td>1 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>5</td>
<td>Acceptable tolerance in level difference between the shaft ends of the drive pulley in vertical plane is 1/1000 of length of the pulley</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Acceptable tolerance in the difference of centerline of conveyor and drive pulley is 10 mm in horizontal plane</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Erection engineer should understand the concept of end floats in bearing and the floating bearing concept. Many of the manufacturers of pulleys provide fixed bearing at one end and floating bearing/ free bearing at the other. This is to accommodate the thermal expansion of shaft during operation which can result in spall of the spherical rollers of the bearing. The locating ring of the bearing plummer block assembly is only in one half in case of floating bearing assembly inorder to give a “play” for the rollers between the inner and outer race. While the alignment check is done for the pulley shaft to gearbox output shaft this play is to be considered while taking the total indicator reading
• While checking the alignment of the scoop coupling input and output shafts, 3 dial gauge indicators – one for checking the radial tolerance and 2 for checking the axial tolerance-shall be used in case roller bearings are used.
• For the gearbox, measure the angularity by using a feeler gauge and ensure a constant gap measured at every 90 degree of rotation by proper adjustment of the input and output shafts
• It is important in many cases to provide supports with some means of adjustment for squaring or leveling such as shims, jacking bolts and slotted holes. Use copper or stainless steel shims onl.
• Use ring washers for the bolt fixing of drive equipments on to the drive base frame so as to ensure proper clamping with the unit even in case of “lazy tightening”.
• While lifting motors, scoop couplings and gear boxes use lifting hooks for the same. Never wrap the slings over the shafts as it may result in the bending of shafts.
• Check for the static balancing of pulley before coupling with gearbox output shaft. If required weld counter weights on to the diaphragm plate to attain the satisfactory result
• The method of mounting of flexible couplings on to the equipment shafts has a clear impact on the level of vibration. For any equipment shaft, in order to avoid the slip, shrink fit between the hole and the shaft is required. Adopting the shaft basis system, the hubs/ half couplings shall be oil heated before mating with the shaft. A very common and erroneous method adopted during erection stage is gas heating of the sleeves which results in non-uniform heat distribution and further thermal-residual stresses.

CONCLUSIONS

Excessive vibrations in the drive chain equipments can be avoided by accounting for all design aspects and religiously following the installation instructions. Careful considerations during the design phase of the drive system combined with a good maintenance regime over the conveyor's life will help ensure a lower vibration level and eliminates sources of un-necessary energy losses. By taking the following design aspects into account, a designer can confidently reduce the possibilities of undue vibrations

- Selecting the motor, coupling, gearboxes with sufficient margin over the calculated theoretical margin
- Motor selection based on the characteristics of the high speed fluid coupling
- Meticulous analysis of the heat loss calculation of reducer taking into account the load dependent power losses as well as no-load power losses
- Suitable bearing selection and L10 life
- Proper material selection of gear coupling
- Sturdy design of drive base frame

Apart from a meticulous design, proper storage at site and erection are required for reducing the drive system vibration levels.

- Maintain the tolerance limit within the acceptable limits as stipulated by the manufacturer
- Take care of the end floats of bearing wherever applicable while performing the alignment
- Use corrosion resistant shim plates and packing plates

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