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Design and implementation of an advanced controller in plant distributed control system for improving control of non-linear belt weigh feeder

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ABSTRACT

A Belt Weigh Feeder (BWF) is a flat belt conveyor designed for feeding bulk material into a chemical process in a controlled fashion for better process control. The dynamic weight of bulk material is measured with a belt weigh bridge and the belt speed is controlled to compensate for any variation in the weight so that the mass feed rate is maintained as per the set feed rate. The problem of belt speed control is challenging as the dynamic response of system is non-linear and there are frequent changes in belt load due to variation in bulk material characteristics. The control accuracy of belt weigh feeder is fully dependent on the controller's performance in providing precise control of speed of motor/belt. Any delay in achieving the set feed rate or frequent deviation between set and actual feed rate affects the quality and efficiency of downstream process. Conventional PI controller is unable to provide optimum control due to system non-linearity. To overcome this problem, in this paper first the operating data of the BWF system is analysed and the nature and cause for the nonlinearity is investigated. The system is then modelled using the design parameters of plant belt weigh feeder, which is then simulated to have a better insight into its non-linear response. Subsequently, based on simulation results, a PI Fuzzy Logic (PI-FL) controller is designed to improve the control accuracy of the system. Further, to ensure the stability of the system, an adaptive controller is introduced in cascade to fine tune the gains of PI-FL controller as per the operating speed of the BWF. Finally, an advanced PI-FL with cascade adaptive controller is implemented in the plant DCS (microprocessor based process control system). The actual test results indicate reduction in the Integral of Absolute Error (IAE) of the system by about 34% using this controller.

1. Introduction

Belt Weigh Feeders (BWF) are used in many mineral/ore, cement, chemical, fertiliser and food industries to measure and control the quantity of the bulk material going across the belt. The belt weigh feeder construction includes a small flat conveyor belt supported on a steel frame which provides the mounting arrangement for feed and discharge end pulleys, weigh bridge rollers and supporting idling rollers. An endless rubber belt moves over the pulleys and idling rollers. A DC motor is coupled to discharge pulley via a gear box as can be seen from Fig. 1(b). The material load is sensed by load cell based weigh-bridge (in kg/m) and accordingly speed of the belt (in m/sec) is varied so that the material feed rate (in kg/min or MT/hr) remains constant at the discharge of the belt weigh feeder as per (1).

$$\textit{Mass flow rate}\left(\frac{MT}{h}\right) = \textit{Belt load}\left(\frac{kg}{m}\right) \times \textit{Belt speed}\left(\frac{m}{s}\right) \times 3.6\,(\textit{Numerical constant}) \quad (1)$$

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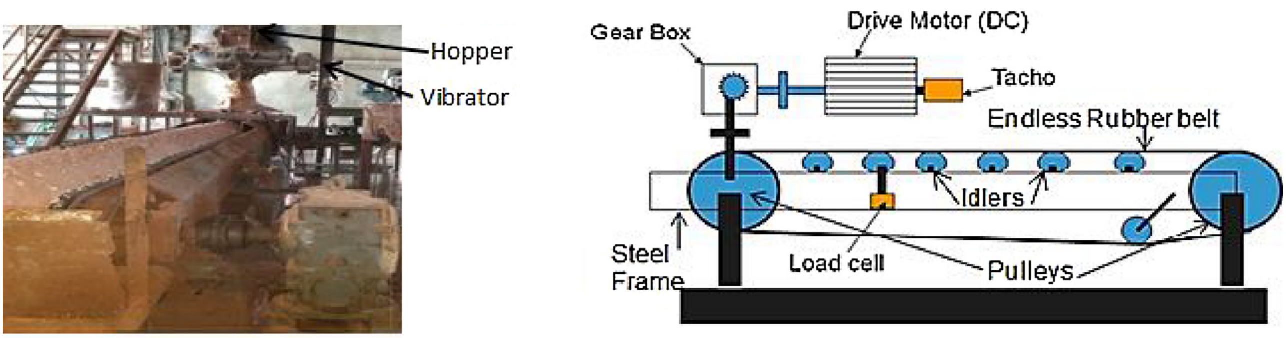

(a) (b)

Fig. 1. (a) Picture of Belt Weigh Feeder (BWF) System (b) Schematic Diagram of BWF construction.

In order to sense the material weight accurately and allow for load cell time constant, weigh feeder belt is driven at a very low speed (less than 0.3 m/s) because of which gear box is required to couple the drive pulley with DC motor.

1.1. Problem statement and literature review

The belt weigh feeder system under study is designed for feeding Rock Phosphate (Tri-Calcium Phosphate) mineral, a key input in the manufacture of fertilizers, into the reactor for reaction with 60% Nitric acid. Rock Phosphate, before being fed on the BWF, is ground into a fine powder in Ball Mill to increase its surface area to achieve better reaction rate. Rock Phosphate, being a mined mineral, has some amount of impurities like silica and metal oxides in addition to moisture which leads to frequent changes in its bulk density. The key problem of BWF process is that feeding of powdered material on the belt is non-uniform as it is fed with the help feeding hopper above BWF. Depending upon the bulk density of bulk material, scaling inside the hopper, moisture and lump content of the bulk material, the feeding rate of material on BWF belt varies continuously. The feeding is coarsely controlled manually by adjusting the gate opening of the feeding hopper and adjusting the vibrating motors attached to feeding hopper to facilitate uniform feeding of material on the belt to the extent possible as shown in Fig. 2. This in turn leads to frequent changes in load cell signal that causes BWF motor set-point to change in order to maintain the mass flow rate constant as per (1). Further, finely ground Rock Phosphate sometimes has a flushing tendency which often leads to abrupt changes in belt load. All these factors in addition to changes in operator set-point requires the BWF controller to continuously adjust the motor and belt speed to maintain the desired feed rate. For example, if the set feed rate is 10 MT/hr and the material load on the belt changes from 25 kg/m to 85 kg/m then the belt speed has to be reduced from 0.111 m/sec to 0.0327 m/sec to maintain the same feed rate.

The accuracy, stability and control performance of Belt Weigh Feeder has a direct bearing on quality of the resulting slurry in the reactor. The slurry viscosity and its moisture content are dependent on the precise control of Rock Phosphate feed rate and directly affect the efficiency of downstream crystallization and filtration process.

Hence, from the point of view of process optimization, it is critical that the plant BWF maintains feed rate as per the set feed rate with excellent control accuracy.

The features of the Belt Weigh feeder system are inertia, time-variant, non-linearity and frequent load disturbance. There are two unstable phenomena which affect the performance and precision of the system, the first one is non-uniform material character such as coarse size, moisture content, and so forth, and the second one is variation of the feed rate set-point [1,2]. The belt feeder exhibits nonlinear behaviour because of motor friction, motor saturation, and sensor noise in the measurement system. The dynamics of the weigh belt feeder is dominated by the motor [3,4]. The separately excited DC motor employed in belt weigh feeders has dead band and friction which affects dynamic response of the system. The experimental study on DC motor friction shows that Coulomb and Stribeck friction causes non-linearity in DC motor model in comparison with viscous friction [5]. The usual practice, however, is to model DC motor with only viscous friction while ignoring Coulomb and Stribeck friction. The constant belt load disturbance, frequent changes in bulk material properties and system non-linearity pose a great challenge on the PI controller which is provided for maintaining motor/belt speed. These factors affect the system inertia, gain and dynamic response at different operating conditions. Proportional plus integral (PI) controller when applicable to DC motor

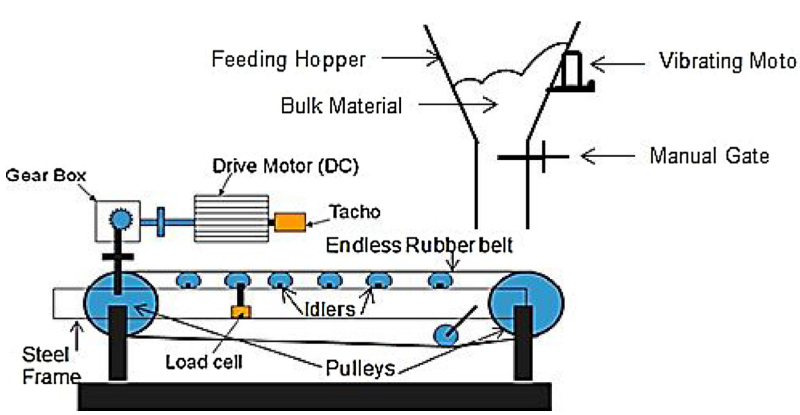

Fig. 2. Schematic diagram of an industrial BWF system with feeding arrangement.