# Development and performance evaluation of servo based PLC operated grain automatic weigher for Flour mill industry

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**ABSTRACT**

Weigher is the necessity of a flour mill either to weigh the clean wheat before 1st break rolls or to weigh the final products to calculate extraction rate. Low cost automatic weighing machine using latest technology of servo control and Programmable Logic Control was developed considering the advantages of electronic weighing and linear motion guide ways moving accuracies. Statistical analysis indicated that there was no significant difference in mean value of measurements from set mass (1500, 3500, 5000g) and measured mass at the 95% probability level. Minimum average percentage error (< 0.2%) was observed for 3500 to 5000g weight measurements. Mass measurements on the dispensed material under repeatability conditions produced results within ± 0.22% of displayed set mass for 3000 to

5000g and revealed that mass measurement of product by auto grain weigher was quite precise. Automatic weigher can be used for mass measurement of granular products in automated production processes.

**Keywords: Wheat**, Weigher, Servo, PLC, Ballscrew, Loadcell

## 1. Introduction

In flour mill industry it is most important that weighers & weighing mechanisms are to be very accurate. Without this accuracy, extraction figures are meaningless. Weigher is the necessity of a flour mill either to weigh the clean wheat before the 1st break rolls or to weigh the final products to calculate extraction rate. In the flour mill industry the quantity of flour produced expressed as a percentage of the wheat used. For more immediate mill control purposes the amount of flour produced from clean wheat on to the 1st break rolls is used (or) is calculated as a percentage on an hourly basis. Rate of extraction can also be calculated based on wheat products. Rate of extraction can have a considerable effect on the production cost of the flour. Also from an overall manufacturing cost stand point, the output per hour or 24 hours can affect the profitability of the whole of operation of the mill. Feed shutter for automatic grain weigher [1] consisted of mechanical gate to provide feed opening/closing for easy handling on the completion of the weighing operation. Solenoid valve and lever mechanism operates gate mechanism which leads to wear and tear of links, arm knife edges etc., two positions either open or close affects the weighing accuracy. Automatic grain weighing machine [2] consisted of hopper, weigher with hooks arrangements for empty bag & drop hole mechanism. Full open to half open or full close of the gate operated through drop hole mechanism was used to fill the specified quantity of matter into the bag which affects the accuracy of weighing. Continuous monitoring of set weight and matter feeding was absent. Conventional filtering methods employed in dynamic weighing systems have limitation in improving accuracy and throughput rate [3]. Fluctuations in the bulk density of the raw materials in volumetric or rotary charger dosing results in alterations in weight [4]. Weighing machines equipped with platform scales or beam balances with dials do not ensure the required accuracy of weighing batch materials [5]. Mechanical scales are not reliably precise and their applications in automatic lines are complicated [6]. Mechanically operated autograin weighers are obsolete and maintenance oriented. Electronic weighers are sophisticated and calibrate themselves by using built in calibration procedures and saves the data themselves [7]. Load cells are widely used in a variety of industrial weighing applications such as wending machines and weighing systems [8]. Load cells interfaced with integrated electronics convert the weight force to an electric signal and deliver the output signal to an automation system [9]. Linear motion guide ways accompanied with precision ballscrew can greatly enhance moving accuracy. Hence, considering the advantages of electronic weighing accuracy and Linear motion guide ways moving accuracy, the present project was undertaken to design and develop state of art technology i.e. low cost automatic weighing machine using latest technology of servo control and Programmable Logic Control (PLC) concepts.

## 2. Materials and methods

### *2.1 Materials:*

Materials of construction used were stainless steel sheet metal (SS 304), Indian standard medium channel, mild steel square tube, load cells, Hopper weighing controller (Bangalore, India), Linear motion (LM) guide ways(Hiwin, Taiwan), AC Servomotor & drive, PLC, Control panel with PLC & Junior man machine interface (MMI) (Chennai, India) were purchased from Balaji Autotech Pvt. Ltd.,(Mysore, India).

*2.2 Equipment:*

The Automatic system developed for weighing grain / grain products is shown in Fig.1. Automatic grain weighing equipment consisted of storage hopper (Approx. 0.04$m^3$ capacity, sheet metal thickness 3.5mm, 100mm Square bottom opening), quantity regulating servo slide, linear motion guide ways with precision ball screw (20mm width, 17.75KN dynamic load rating, 37.84KN static load rating, 16mm diameter ballscrew), AC Servomotor (1.27Nm torque, 3000 rpm, 400 watts) with drive (220 volts, single phase), weighing hopper (5000g capacity, sheet metal thickness 2.5mm, 75 mm square bottom opening), load cells (10000g capacity), weighing controller (Programmable high precision micro controller based indicator with 16-character, 2-line liquid crystal display), programmable logic controller (Micro PLC, 16/12 digital Input / Output) and pneumatic cylinder (6 Bar operating pressure) with gate, supporting structure-1 for storage hopper (1.4m height, 0.53m square length & width), and Supporting structure-2 for weigh hopper (0.05m square pipe, 0.7m height, 0.38m square length & width).

*2.3 Design consideration:*

2.3.1 Storage and weigher hoppers:

Storage and weigher hoppers were designed for 25kg & 5 kg holding capacity respectively by considering Bulk density of wheat as 76 kg per hectoliter weight and shape of the hopper as frustum of pyramid. Volume (Vol) of hopper was calculated using equations (1) and (2)

Vol = Mass/ Density (1)

Height (H) of the hopper was calculated by using equation (2)

Vol of frustum of pyramid hopper = $H [A1 + A2 + (A1A2)^{0.5}] / 3$ (2)

Where A1= Area of bigger end of hopper (Inlet length x width)

A2= Area of smaller end of hopper (outlet length x width)

H= Height of hopper

2.3.2 Load cells:

Load cell capacity was calculated by considering the weight of weigher hopper, discharge material weight, weigher hopper location pins and weigher hopper discharge gate.

Load cell capacity = (weight of weigher hopper+ discharge material weight + weight of location pin+ weight of weigher hopper discharge gate)

Load cells with metrological characteristics such as class III accuracy, 10kg maximum capacity, 1.5 ± 0.01 mV/V rated output, combined error of % ± 0.05% of rated output, repeatability of ± 0.05% of rated output, 5-70$^0$C operating temperature range, 200% of safe overload and 300% of ultimate overload were selected

 

2.3.3 Pneumatic cylinder:

Double acting piston pneumatic cylinder was selected for the operation of weigher hopper. In-stroke and out-stroke forces of pneumatic cylinder were calculated by equations (3) and (4)

$$F_1 = P_p\pi(d_1^2 - d_2^2)/4 \quad (3)$$

$$F_2 = (P_p\pi d_1^2)/4 \quad (4)$$

Where $F_1$ = In-stroke force

$F_2$ = Out-stroke force

$P_p$ = Pneumatic cylinder air pressure

$d_1$ =Bore diameter of cylinder

$d_2$ =Piston rod diameter

2.3.4 Linear motion guide ways:

Linear motion guide ways series suitable for lathe applications were selected and model size was determined based on ball screw diameter used. Four numbers of linear guide ways blocks were considered.

*2.4 Methods:*

Sheet metal work and welding was carried out to manufacture storage hopper, and weigher hopper using stainless steel (SS 304) sheet metal. Hopper gates assembly were manufactured by using mild steel plates with chromium plating. Bearings were used for frictionless sliding movement. Supporting structure channels (ISMC-75) were cut to a length of 1.4m and storage hopper supporting frame ($0.53m^2$) was fabricated. Storage hopper and LM guide ways were assembled on supporting structure. Mild steel square pipe (0.05 square meters) were cut to a length of 0.7m and weigher hopper supporting frame ($0.38m^2$) was fabricated. Load cells were assembled on weigher hopper supporting frame. Weigher hopper location pins were manufactured and fastened to the weigher hopper. Weigher hopper location pins were aligned with load cells and mechanical stoppers were adjusted. Double acting piston pneumatic cylinder was connected to the weigher hopper gate and pneumatic connection was provided. AC servomotor was coupled to the ball screw of LM guide way. Position limit switches and reader micro switch were assembled on aluminum track which was mounted on LM guide way. LM guide was connected to storage hopper gate by suitable bracket. Control panel with weigher controller (Fig.2) and necessary electrics was interfaced with load cells. AC servo drive controller (Fig.3) with PLC, MMI, servo drive and electricals were assembled in a panel and interfaced with servo motor and micro controller.

**3. Calibration of the weighing system:**

 

Empty weigher hopper was ensured before tare operation. After tare, known weight was placed in the weigher hopper and value of the weight with an average fluctuation factor for three set of readings was entered in the micro controller using numeric keys. Value displayed on microcontroller was considered as the calibrated value.

*3.1 Operation of equipment:*

Material mass to be weighed was fed to storage hopper. Gate open constant weight, gate open speed, feed weight and weight time for door close parameters were set on MMI. Zero limit, set high, zero delay, over load, auto/manual, set delay and span load parameters were programmed on micro controller. Pneumatic pressure in the pneumatic line was confirmed to the required value. Weighing cycle operation was carried out by pressing F1 (cycle start) key on MMI touch pad.

*3.2 Equipment performance evaluations:*

Performance evaluation of the equipment was carried out by operating the equipment to measure mass of 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500 and 5000g. Discharged material from the weigher hopper was weighed on Essae – Teraoka Ltd., model: PG 10000 table top electronic balance (maximum weighing capacity: 10000g, readability (d):0.1g, linearity ± 2d). Grain weigher cycle time for 500g and 5000g was recorded. Repeatability limit for grain weigher was calculated by using equation (5)

$$\text{Repeatability} = 1.96[(2\ S_r^2)]^{0.5} \quad (5)$$

Where $S_r$ = Repeatability standard deviation

**4. Statistical analysis:**

Ten replications were carried out for each measurement and data obtained were analyzed statistically for analysis of variance (ANOVA) to test for any significant differences in the mean values of all the groups and regression analysis to predict the accuracy of mass measurements were carried out by using Microsoft Excel software.

**5. Results and discussion**

Wheat used for mass measurement experiments had the following characteristics on dry basis: 9% moisture, 7600g per hectoliter weight, 32g weight per 1000 kernel weight and hardness value of 10000g per grain. Above parameters indicated that wheat used was medium hard type. Prototype automatic weigher was developed and performance evaluation was carried out experimentally. Total 90 experiments were conducted for test mass measurement of 1000g to 5000g with an incremental value of 500g. An ANOVA of weight differences for the 9 runs with 10 measurements per run showed that there was no significant difference in mean value of weight measurements ($p>0.05$) from table top electronic balance and grain weigher. The average percent weight difference was 0.26%. Statistical analysis performed on the averages of percent weight differences indicated that the mean of the percent weight differences between measurements by grain weigher and those by table top electronic balance was 0.28% with a standard deviation of 0.18%.

Table1. shows comparison of set mass and measured mass of wheat samples. p-values for 1500, 3500, 5000g were 0.889, 0.068 and 0.48 respectively. $F_{statistical}$ values for 1500, 3500, 5000g were 0.019, 3.766 and 0.507 respectively. $F_{critical}$ values for 1500, 3500, 5000g were 4.414, 4.414 and 4.098 respectively. $F_{statistical} < F_{critical}$ and p-values > 0.05, there is no statistical difference in mean value of measurements from set mass and measured mass. For 1000, 2000, 2500, 3000, 4000 and 4500g, P-values < 0.05 and $F_{statistical} > F_{critical}$ indicated that there is a significant effect due to mass measurements at the 95% probability level. Differences could be minimized by proper tuning of storage hopper gate open speed, feed speed and close rapid speed parameters. Average percentage error was observed from 0.1% to 0.6%. Minimum average percentage error (< 0.2%) was observed for 3500, 4000, 4500 and 5000g mass measurement. Maximum average percentage error (>0.2% and <0.6%) was observed for 1000, 1500, 2000, 2500 & 3000g mass measurement.

This could be further minimized by altering the position of reader limit switch and by tuning of storage hopper gate open speed, feed speed and close rapid speed parameters. mass measurements on the dispensed material under repeatability conditions produced results within ± 0.22% of displayed set weight for 3000,3500,4000,4500 and 5000g. Repeatability of greater than ± 0.22% was observed for 1000, 1500, 2000 and 2500g displayed set mass which was due to material measurement speed. Improvement in repeatability limit could be possible by slowing down weigh up cycle. Cycle time of weighing process for minimum and maximum test mass measurements of 500g and 5000g were 14s and 23s respectively, which are very appropriate and suitable for the next process. Weight measurements recorded by the automatic grain weigher (dependent variable) and table top electronic balance (independent variable) yielded regression equation (y=1.0014x – 3.667) with a slope of 1.0014 with an adjusted $R^2$ of 0.9999. $R^2$ and slope of the regression model was close to unity showed that automatic weigher was measuring accurately.

## 6. Conclusion

Weigher is the necessity of a flour mill either to weigh the clean wheat before the 1st break rolls or to weigh the final products to calculate extraction rate. Rate of extraction can have a considerable effect on the production cost of the flour. Low cost, servo based PLC operated grain automatic weigher was developed and performance evaluation was carried out experimentally.

The results of studies indicated that the equipment met the needs of weighing process. Statistical analysis indicated that there was no significant difference in mean value of measurements from set mass (1500, 3500, 5000g) and measured mass at the 95% probability level. Minimum average percentage error (<0.2%) was observed for 3500, 4000, 4500 and 5000g mass measurements. Mass measurements on the dispensed material under repeatability conditions produced results within ± 0.22% of displayed set mass for 3000,3500,4000,4500 and 5000g revealed that weighing of product by auto grain weigher is quite precise. Adjusted $R^2$ and slope for the regression equation between weights measured by the automatic weigher and by table top electronic balance was very close to unity. Accuracy and repeatability of the automatic weigher are found to satisfy the flourmill requirements of grain weighing process.

Automatic weighing equipment can also be successfully used for weighing and dosing of any granular products into bags, containers in automated production processes.

 

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**References**

[1] Shimauch, Y., Feed shutter for automatic grain weigher. Japan patent No.2000053101-2000-02-22.

[2] Okada, S., and Shimauchi, Y., Automatic grain weighing machine. Japan patent No. 2001165756-2001-06-22.

[3] Halimic, M., Balachandran., and W Enab, Y., IEEE Xplore 0-7803-3645-3/96, *1996,* p. 2123

[4] Efremenkov, V.V., Subbotin, K. Yu., and Khaimovich, M.M., *Glass and Ceramics,* 2001, Vol. 58, p.195.

[5] Efremenkov, V,V., Subbotin K,Yu., Klimychev, V.N., Ruchkin, V.V., and Khaimovich, M,M., Glass and Ceramics. 2003, Vol. 60, p.129.

[6] Bubulis, A., Jurenas, V., and Kranclukas, R., *Mechanika,2005, Vol.* 6( 56), p.33.

[7] Gustavo, G.A., and Angeles, H.M., Accredited quality assurance, 2007. vol.12, p. 21

[8] Jafaripanah, M., Al-Hashimi, B.M., and White, N.M., ( 2004). Design consideration and implementation of analog adaptive filters for sensor response correction. In Proceedings of the 12th Iranian Conference on Electrical Engineering (ICEE2004), 11-13 May 2004, Mashhad, Iran. p. 109

[9] Dynamic weighing and dosing with Fast Intelligent Transducers. FIT.http://www.imeko.org/publications/tc3–2002/IMEKO-TC3-2002-024.pdf.

 

TABLE 1: Comparison of set weight and measured weight of wheat

| | Mass set (g) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 |
| | Measured values (g) | | | | | | | | |
| Max. | 1016.2 | 1510.6 | 2015.1 | 2508.9 | 3016.6 | 3511.6 | 4010.5 | 4504.4 | 5015.9 |
| Min. | 1000.6 | 1493.7 | 1980.2 | 2483.9 | 3000 | 3495.1 | 3999.6 | 4488 | 4988.2 |
| Average | 1006.8 | 1499.8 | 1991.5 | 2494.8 | 3008.3 | 3502.6 | 4005.5 | 4495 | 5001.1 |
| Standard Deviation | 4.8 | 5.1 | 9.2 | 6.6 | 4.8 | 4.3 | 3.8 | 4.8 | 7.0 |
| Error (%) | 0.6 | 0.26 | 0.57 | 0.28 | 0.27 | 0.1 | 0.13 | 0.13 | 0.1 |
| p-value | 0.0002* | 0.889** | 0.009* | 0.023* | 3.2E-05* | 0.068** | 0.001* | .003* | 0.48** |
| $F_{crit}$ | 4.414 | 4.414 | 4.414 | 4.414 | 4.414 | 4.414 | 4.414 | 4.414 | 4.098 |
| $F_{stat}$ | 20.289 | 0.019 | 8.423 | 6.103 | 30.273 | 3.766 | 20.244 | 11.055 | 0.507 |
| df | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 39 |
| Repeatability | 13.3 | 14.14 | 25.5 | 18.3 | 13.3 | 11.91 | 10.53 | 13.30 | 19.40 |

Fcrit:Fcritical, Fstat:Fstatistical, df:Degree of freedom

Significant at *p<0.05 and not significant at **p>0.05 among test weight samples, n=10

 

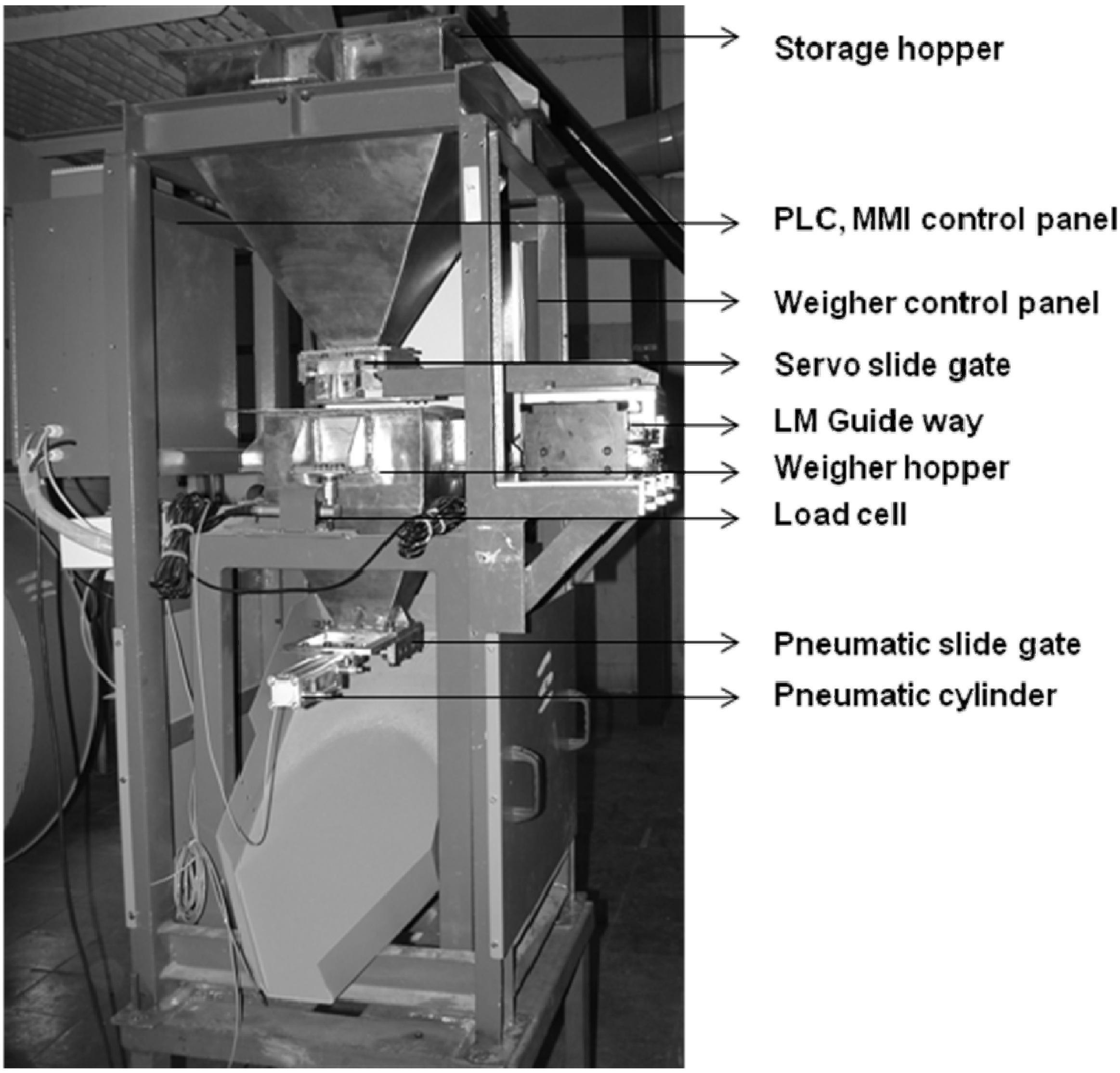


**Fig. 1. Parts of Auto grain weigher**

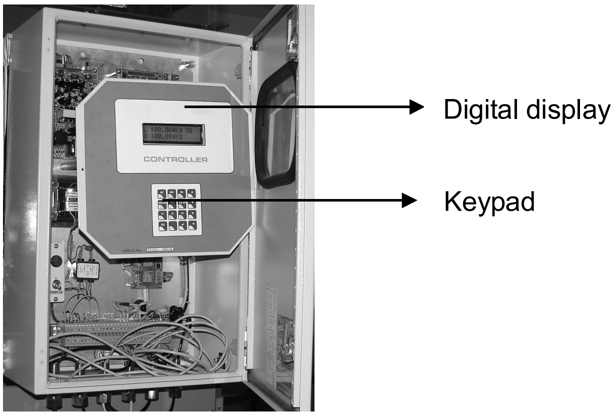


**Fig. 2. Weigher controller**

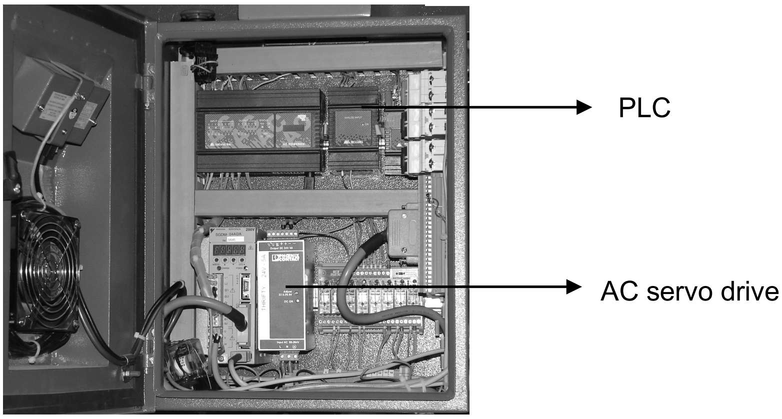


**Fig. 3. AC servo drive controller**