Design of Double Closed Loop for Granular Material Automatic Weighing System

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Abstract. The weighing of granular materials is generally implemented through the detection and control of weighing instruments, which control the vibration intensity according to the weight of incoming material measured by the sensor, and finally assure the material weighing accuracy under certain speed. Vibration feeding equipment is classified into crude feeding and fine feeding. The former is at high rate but with less accuracy while the later is with high accuracy but at lower rate. The final weighing accuracy depends on the aerial weight of material during fine feeding process. The aerial weight can be set, but is still influenced by many factors. Here, in this paper, these factors will be discussed and analyzed. Furthermore, an instrument of dual close-loop of accuracy and feeding rate was designed. This instrument adopts STM32 microcontroller as the processor and applies high-speed 24-bit AD conversion chips in the analogue sampling part and performs well in practical application, solving the longstanding practical difficulties that easier to control static accuracy while hard to control dynamic accuracy.

1. Introduction

Automatic weighing of granular material currently used in the market is designed mainly through volumetric method and weighing method. Volumetric method, such as screw arbor scale, measures the weight of materials by measuring the volume of materials. So this method is simple, fast but with poor measuring accuracy. The quantitative measuring accuracy of volumetric method mainly relies on the density of material, which substantially affected by physicochemical properties of the material, for example, the loose degree, size and uniformity coefficient of granule, hygroscopicity, solubility. All those factors are easily affected by a large quantity of factors such as environmental temperature & humidity, time of exposure to air, and material temperature, etc. in the other hand, weighing method is to measure the quantity of material according to their weight, which uses electronic weighing equipment (mechano-electronics device) to weigh. Comparing with volumetric method, weighing method is more complicated, measuring speed is relatively slow, but with higher weighing accuracy. Weighing method is highly adaptable, so the weighing material and the quantitative value could be flexibly changed, while realizing the technology of dynamic quantitative weighing with high weighing accuracy and speed. The realization of “two highs” is also one of the difficulties in the field of metering. The current weighing range of electronic scale in china is 29 kg～100 kg, with similar metering accuracy and speed as well as other performance index to those in other countries. Nevertheless, the performance of electronic scale with smaller metering range less than 25 kg, especially for metering between 0.5 kg to5 kg, is much lower compared with oversea similar products. Here, the author discovered that the gap mainly lies in meter through numerous practice and deep research and analysis. The oversea meters can always function effectively under any conditions like system voltage change, feeding pressure change, atmospheric pressure change and even in different electromagnetic environment, which ensures both accuracy and speed. Yet, the domestic meter might be currently with desirable accuracy and speed after commissioning, the accuracy or speed may become lower several days later. As for the dynamic characteristic, domestic meter is different with the one from oversea countries. Based on the discovery, author redesigns the weighing meter, so the model selection of chip and layout of circuit board can be scientific and logical. The double closed loop control added in the software of system successfully solves the conundrum of “two highs”.

2．Operating Principle of Automatic Weighing Machine

Granular automatic weighing machine system consists of two parts: mechanical and electrical parts. Mechanical part comprises material storage, loading head and charging spout; electrical part comprises vibratory feeder, weighing instrument, weighing cell, gate open motor, feed distributor, and human-computer interface. Generally, vibratory feeder, weighing instrument, weighing cell, charging spout and gate open motor form a complete set. Each single weighing meter is connected with weighing cell, gate open motor, gate open position sensor and vibratory feeder，as shown in Fig.1：

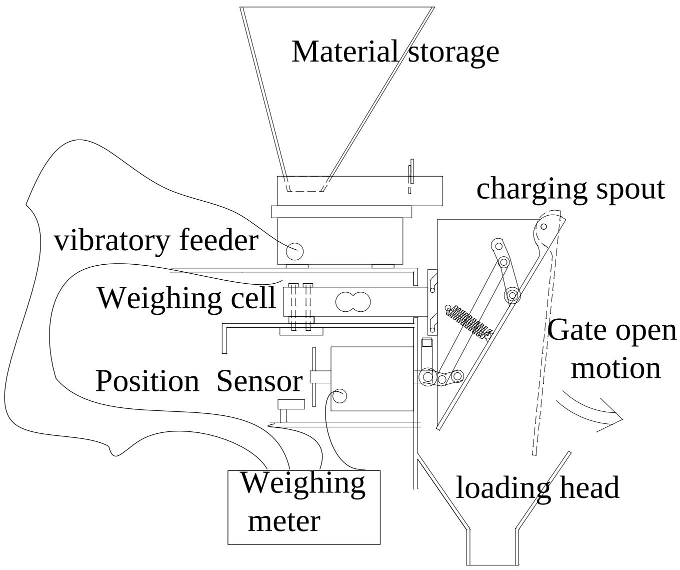

Fig. 1 schematic drawing for single way automatic weighing machine system

The system loads material through material storage, and then feeds through vibratory feeder, with weighing instrument controlling the vibration intensity. The vibration intensity can be generally divided into three kinds: two-phase, three-phase and stepless adjustable vibration, among which two-phase vibration is mostly used. In this article, we take two-phase as our research object.

The controlling process of system: charging spout connects with weighing cell, and charging spout receives the blanking from vibrator, while checking the weight of blanking through sensor. When starting automatic weighing, the weighing instrument first enables vibrator to start vibration feeding through crude feeding form, which is a large amplitude mode of vibrator, with the features of fast feeding, but with large deviation of weight of material in charging spout with target weight after ceasing. When the blanking value tested by meter is close to weighing value, switch to fine feeding, which is a small amplitude mode of vibrator. The weight of material under this mode after stopping the vibration is highly accurate, but feeding process slow[6]. Therefore, both high speed and high accuracy can be realized from crude feeding to fine feeding under the control of meter. A significant concept of aerial weight mentioned here, means: a stopping signal sent to vibrator after detecting one stopping value by the instrument, since some materials are still in air during falling, the actual weight of material is higher than that when sending stopping signal, so the extra weight is aerial weight. Aerial weight not necessarily means the weight of material in the air[5], but related with scanning period of microcontroller, and affected by many factors.

Set 8-spout scale as an example, which means having 8 sets of such equipment, and 8 charging spouts like this. Each spout is operating independently, and ready for feeding after weighing. If a feeding signal is detected by feeding controller, then select one feeding motor of charging spout, switch feeding gate to feed. Under the control of weighing instrument, the charging spout shall open gate——time delay—— close gate—— start up to re-weighing. The working flow is as follows:

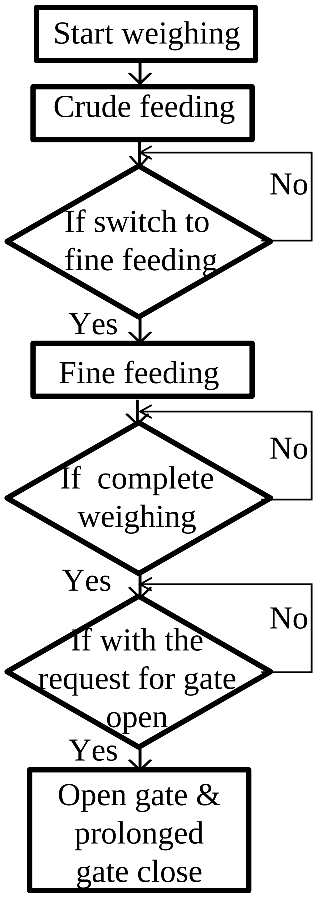

Fig.2 working flow of automatic weighing machine

As for the system composition of 8-spout scale, except for the 8 sets of equipments on the machine and common used material storage and loading head, there are 8-channel instruments, 8-channel weighing cells, 8-channel gate open motors, one touch screen and one feed distributor, as shown in Fig.3:

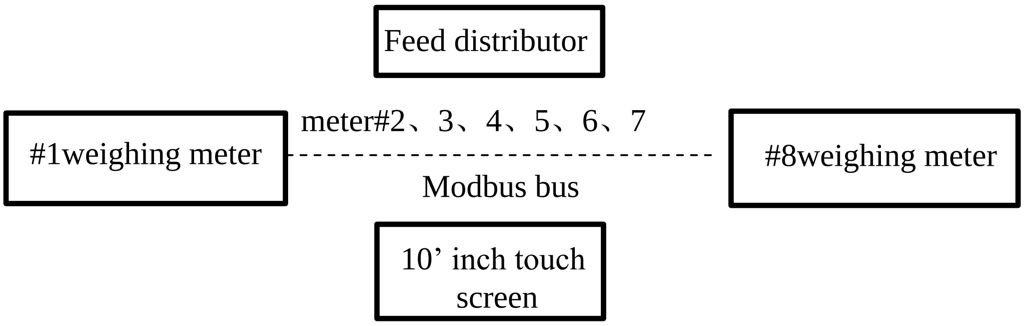

Fig.3 schematic drawing of electrical system wiring

3．Hardware and Circuit Design for Weighing Instrument

The following is based on measuring range：200g, Packing rate：≥40 package / min, dynamic error±0.2g parameter considered. Select domestic brand of ZEMIC (Zhonghang Electronic Measuring Instruments Co., Ltd) weighing cell 20kg-L6C. Adopt relatively new 24-bit analog-digital conversion chip AD7190 produced by US AD company. The index of this chip, compared with previous ones such as: AD7730, AD7729, is one magnitude higher. AD7190 chip possesses merits like ultra-low noise, 50 Hz/60 Hz power frequency suppression circuit, input programmable gain, ultra-high conversion rate etc. The weighing cell bridge circuit directly connects with AD7190 through filtering. The interface of this chip with microcontroller is SPI interface[1], and microcontroller adopts 32-bit high-performance ARM Cortex-M, and the speed of Cortex-M3 is higher by 30% than ARM7, with lower power dissipation, which can reach 72MHz after the timepiece adopting internal PLL (phase locked loop) frequency multiplication[4]. The outstanding property is largely improved compared with early-stage microcontroller 51, AVR etc. The system chart of instrument following is shown in Fig.4.

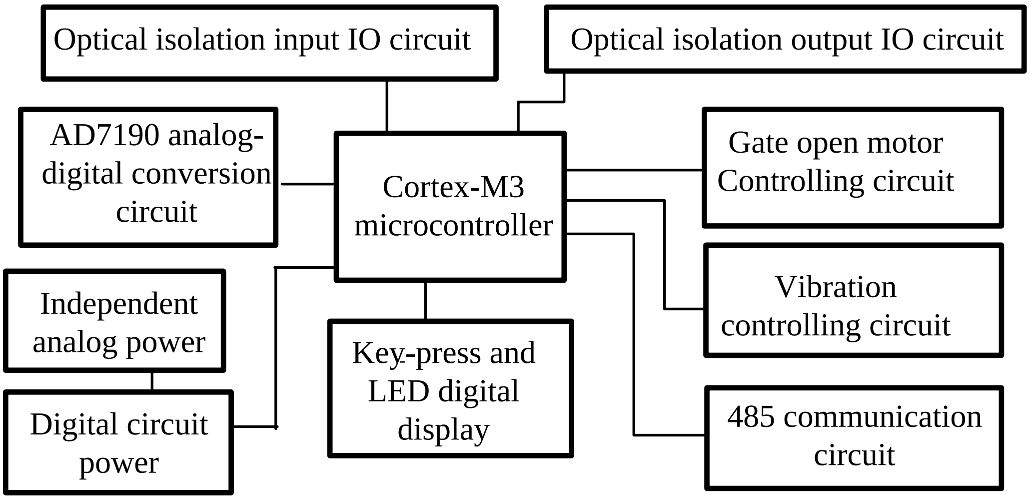

Fig.4 weighing instrument system chart

The instrument adopts independent analog power and multiple filter power, which makes analog-digital conversion more accurate. Digital power supplies power to digital circuit, including analog-digital conversion AD7190 module numeric portion. The AD7190 wiring principal is as shown in Fig.5：

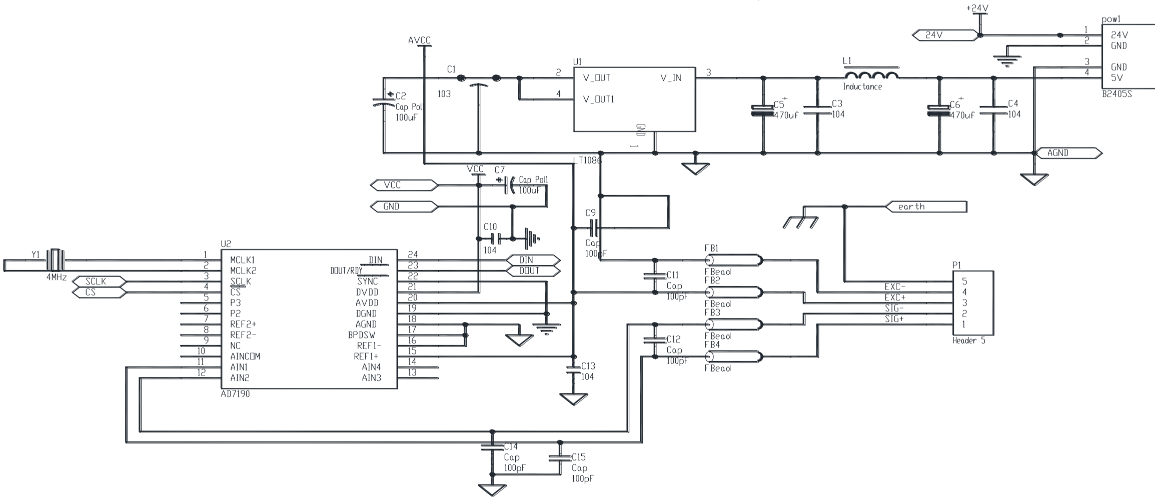

Fig.5 AD7190 Wiring diagram

Schematic diagrams for other parts are omitted.

4. Crude Feeding & Fine Feeding Control, Aerial Weight and Error Analysis

For more efficient analysis, we would adopt backward induction. Suppose 8-spout scale would pack 200g, based on the measuring rate of over 40 package per min, with 8 channel apportion. In order to improve the reliability, suppose channel 1 has fault, and calculate according to channel 7 satisfactory speed, then will be 60 seconds/40 package, then each channel uses 1.5 second to open gate for feeding. When the rest 6 channels opening gate for feeding, being the time for the measuring of this channel, which is calculated to be 9 seconds, based on channel 6 time spend (1.5*6=9). That is, finish the weighing of 200g material in 9 seconds, deducting 1 second of error time, which means to finish weighing in 8 seconds. Through numerous tests and former experiences, fine feeding completing around 5g in 3 seconds is suitable, which means complete 1.67g per second. Author selects the sample of 300 times per second, under this speed, AD7190 can also reach 22 bit valid data. While rude feeding time should be within 5 seconds, while feeding speed is 195 g / 5 seconds, being 39 g. The metering error of each channel should be 39g /300=0.13g, because digital circuit error is a quantization error of ±1, based on which, the error is ±0.13g, while the actual error is much larger than this. The reason is when inspecting switching weight, the change of aerial weight is non-measurable. The actual switching error of crude feeding after metering is ±1g, while the speed of fine feeding is far lower than the speed of crude feeding, the theoretical value is 1.67*1g/39g=0.043g, but the actual result is different. Under this condition of such little weight, voltage pulsation, power harmonic wave, surrounding air, feeding pressure, material density, air vibration, radio wave, air humidity, temperature, feeding temperature etc, can all affect weighing result, among which, the biggest affecting factor is air current generated by material flowing during feeding, and the vibration generated when material hitting the charging spout, and the error is around 0.3g through metering, with normal distribution as shown in Fig.6：

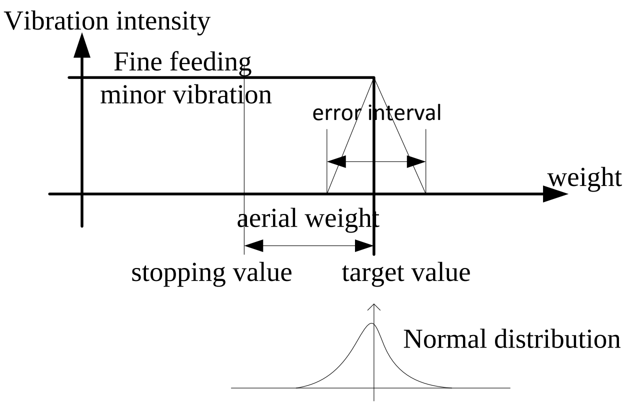

Fig.6 distribution map of error intervals for fine feeding

This is an ideal state, without absolute error, only with random error, from which we can conclude: target value= stopping value + aerial weight, so the random error is ±0.3g, which is acceptable, but some factors can bring the absolute error, like voltage lowed by several Volt, and the result is influencing aerial weight due to the change of vibration intensity. Therefore, the error becomes apparent or speed is lowered.

For crude feeding, switch 2g less (then should be 193g), then cost 1.2 second more per set, and cost 9.6 seconds more for 8 sets per minute. Thus, the things could be done in 60 seconds now need 70 seconds. Although the accuracy reaches standard, the speed is lowered.

In a word, the absolute error cannot be eliminated. As a segment of automatic packing line, it cannot meet the requirement of production if it cannot be solved, therefore, both speed and accuracy cannot reach standard.

5. Double Closed Loop Controlling System Design

Random error can be eliminated through averaging numerous data, and the rest is actual target value, while the difference with target value is absolute error. Actual target value= stopping value+ aerial weight. However, there is a difference between target value and actual target value due to the absolute error existing in aerial weight, which is called absolute error of target value, as shown in Fig.7: the actual target, corresponding to areal weight, is the value A of areal weight, and the target value, corresponding to areal weight, the value B of areal weight. The difference between the value A and B is the absolute error.

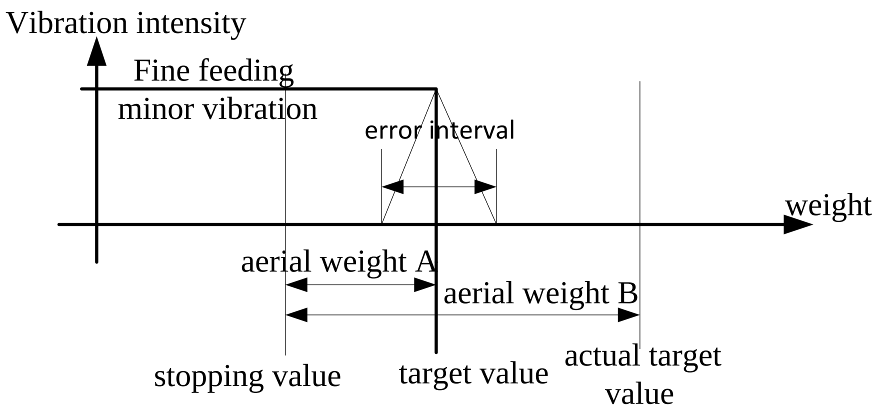

Fig.7 the difference between actual target value and target value is absolute error

Keeping target value unchanged, calculate the adjusted value of aerial weight to eliminate absolute error. Stopping weight = target value - aerial weight, with the key to acquire actual target value which is used to get a difference with target value so as to adjust the value of aerial weight. The author finds one best moment to acquire target value through observation, being the moment immediately before feeding of each scale. The moment to wait for feeding is equivalent to static weighing. The value acquired at this moment is also used for calculating percent of pass through sending to touch screen, which is most close to actual value, using which to minus target value, then the absolute error could be acquired to adjust the value of our aerial weight, so that the absolute error can be eliminated. The specific process is as shown in Fig.8：

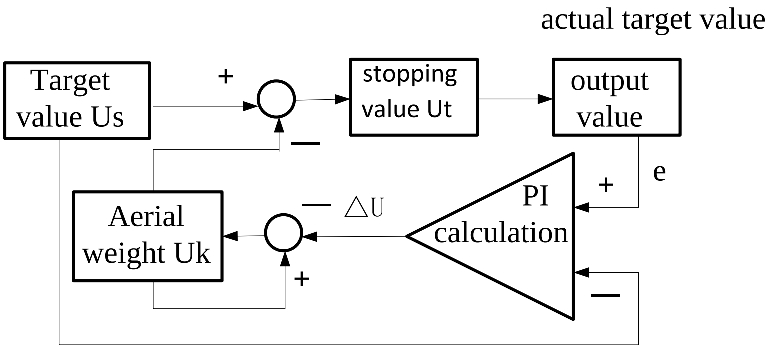

Fig.8 precision closed loop controlling diagram

Expressed as the formula：$\Delta u(n) = Kp\{e(n) - Us\} + \{\frac{T}{Ti}\sum_{i=0}^{n}(e(n) - Us)\}$

Value of aerial weight：$Uk(n) = Uk(n-1) - \Delta u(n)$

stopping value：$Ut(n) = Us - Uk(n)$

Us is a set value, Ut is stopping value, Uk is aerial weight, and e is a static test value[2].

The principle to confirm the stopping value of crude feeding is same as above. Normally, the weighing speed could be assured as long as the time for fine feeding kept around 3 seconds. If time is too short, then the accuracy cannot be ensured, because the crude feeding value is too close to target value. If time is too long, then the total weighing time could be prolonged. Set 3 seconds as a comparison basis. Over 3 seconds, then bring forward the switching value of crude feeding; if less than 3 seconds, then push backward switching value of crude feeding. Since the system has some speed margin, the extraneous factors disturbances will not bring big influence provided that the parameter can be reasonably set, and system can adjust by itself. The detailed calculation method is as shown in Fig.9:

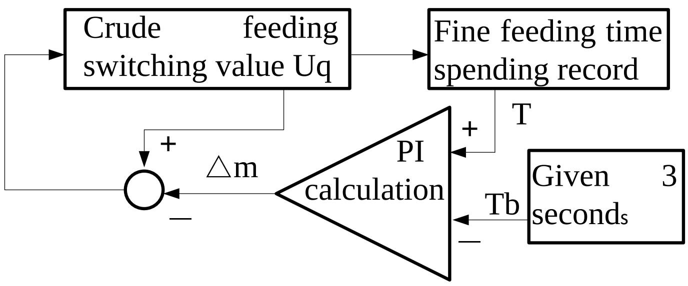

Fig. 9 speed closed loop controlling system

The above algorithm can be expressed as: $\Delta m(n) = K\{T(n) - Tb\} + \{\frac{T}{Ti}\sum_{i=0}^{n}(T(n) - Tb)\}$

Switching value can be expressed as： $Uq(n) = Uq(n-1) - \Delta m(n)$

Tb is a set value, normally around 3 seconds. T is a measured value of fine feeding, m is an adjust value, Uq is a switching value, and K is coefficient of proportionality[3].

3 seconds is just a set value, which could be adjusted properly during testing, e.g. 2.5 seconds etc. as long as suitable. Double closed loop functions simultaneously while independent to each other. The above parameters could be set by touch screen, and can be reckoned into memorizer through establishing memory system and when values like switch value and aerial weight etc. reach certain amount, to be ready for loading when starting up next time, showing its high intellectualization.

6. Experiment and Summarization

Before adding closed loop, test parameter of percent of pass without adjusting parameter for consecutive 3 phases, test for consecutive 10 working days per phase, with data as follows：

Table1. Parameters of percent of pass for consecutive 10 working days of 3 sets before adding closed loop

	1	2	3	4	5	6	7	8	9	10
1	99．7	98．5	98．6	98．5	97．5	96．6	97．5	96．6	95．6	93．4
2	98．7	98．3	98．8	95．4	96．3	94．8	95．3	94．2	95．3	96．1
3	99．2	99．0	97．4	98．2	96．3	95．4	95．7	94．5	94．6	94．5

After adding double closed loop, test without adjusting parameter for consecutive 3 phases, and each phase records the testing data of 10 working days. The overall percent of pass is largely improved, reaching a higher application level;

Table2. Parameters of percent of pass for consecutive 10 working days of 3 sets after adding closed loop

	1	2	3	4	5	6	7	8	9	10
1	99．4	99．3	99．6	99．2	99．6	99．2	99．3	99．6	99．7	99．2
2	98．2	98．5	98．8	99．2	99．2	99．5	99．3	99．5	99．3	99．4
3	98．7	98．8	99．2	99．3	99．4	99．3	99．4	99．5	98．8	99．5

Through variance analysis, we get the following results：

Table 3. Through variance analysis before and after adding closed loop

Set	Number under observation	Sum	Average	Variance
Before adding closed loop	30	2900.5	96.68333	3.126264
After adding double closed loops	30	2976.9	99.23	0.120793

Variances in the above experiment show that, the stability of percent of pass is significantly improved after adding double closed loop. However, before adding closed loop, once the percent of pass becomes worse, it is a must to re-set parameter to adjust percent of pass back to normal. While after adding double closed loop, the system can keep relatively high percent of pass, and ever better and better. Compared with the similar instrument abroad, under the condition of the same speed, it has reached the percent of pass similar to that of foreign instrument.

7. Conclusion

For the weighing of granular material, the double closed loop automatic weighing system designed by the author is applicable to various types of auto-weighing, and is able to set automatic weighing for different weight through repeated tests in weighing and packing line. The experiment tests the disturbance to weighing cell by different factors, including voltage, feeding pressure, temperature, humidity, external vibration, radio wave, etc. The result indicates that the weighing system can meet the requirement in both speed and accuracy, and even with large margin, which reaches a new step in design level. At the meantime, the new designed system raises the interference immunity of facility, reaching the level of oversea similar facility. The automatic adjusting system lowers the personnel operation intensity, and the higher percentage of pass can save large quantity of packaging material for corporation, and improve the packing efficiency, while each index can meet the requirement of corporation.

8. References

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