Development of 400 Newton Spring Weighing Machine

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Abstract- **The weighing machine has spring wire diameter $3\,\mathrm{mm}$ with $20\,\mathrm{coils}$ and external diameter $30\,\mathrm{mm}$. The objectives of this work are to develop and determine the performance evaluation of the mechanical spring weighing machine of $400\,\mathrm{Newton(N)}$ that will be of high resolution and easily operated with simple mechanism. The performance of the weighing machine was done with simple standard weights of different loads placed on the weighing machine The test carried out gave one revolution and $50\,\mathrm{degrees}$ full scale deflection at maximum load of $400\,\mathrm{N}\,(40\,\mathrm{kg})$ with initial sensitivity of $1\,\mathrm{degree}$ deflection caused by a load of $100\,\mathrm{g}$. The modulus of rigidity of the spring used, $\mathrm{G_{steel}} = 80\,\mathrm{GN/m^2}$. The spring weighing machine is for the weighing of bulky materials or packed piece in the laboratory. The efficiency of the machine is $93\,\%$.**

Keywords- Development, Spring, Weighing, Machine, Efficiency.

I. INTRODUCTION

A mechanical spring weighing machine of $400\,\mathrm{Newton(N)}$ is to be designed, fabricated and tested for laboratory purpose. The weighing machine consists of casing cabinet, helical coil spring, dial indicator scale, pointer, rack and pinion gear. If the result of the weighing system is to be meaningful these two requirements must be met in the act of measurement: the standard which is used for comparison must be accurately defined and commonly accepted and the procedure and apparatus employed for obtaining the comparison must be provable.

The mechanical weighing systems employ the three basic elements of measuring systems: Detecting and measuring elements (transducer) which detects the physical variable to be measured (measurand) and converts the signal in to a more usable form; intermediate stage which modifies the signal from the transducer so that a desirable output is available and indicating or recording device.

The spring represents the transducer as it converts the weight of the physical quantity into a mechanical displacement of the springs. The rack and pinion gearing constitutes the intermediate stage as a relatively small displacement at the end of the springs is amplified to give a relatively large displacement of the pinion. The indicator scale consists of the pointer and dial; in which the dial is calibrated in weight units and thus the pointer gives an indication of the weight acting on the springs.

Scale or Balance weighing either mechanical or electronic device commonly used in households, scientific laboratories, businesses and industry to measure the weight or mass of an object or substance. Spring device made of an elastic material that undergoes a significant change in shape or deformation, under an applied load. Springs are used in spring balances for weighing, for the storage of mechanical energy and also used to absorb impact. The specific form of a spring depends on its use. A weighing spring is normally wound as a helix and its elongation is proportional to the applied force, so that the spring can be calibrated to measure this force.

The weight of an object may be determined by using either a comparative method, as with a chemical-laboratory balance or by measuring the gravitational force directly by means of a spring scale. The deflection of a spring scale depends on the local gravitational attraction. Weighing is performed by comparison and is independent of the specific magnitude of the local gravitational attraction, (Encarta Encyclopedia, 2009).

Weighing and measuring are an important and often vital part of our existence. Our bodies, the food we eat and all the products we use as an integral part of modern living, have been weighed and measured at some stage in their development hence the weighing measurement is the act of the result of a qualitative comparison between a pre-defined standard and an unknown magnitude, (Beekwith and Roy, 1985).

Mechanical weighing machine systems originated in Egypt, and were used as early as 500B.C. The earliest devices were of the cord and equal arm type traditionally used to symbolized justice. Unequal arm balances were apparently first used; this device called a Danish steelyard was described by Aristotle (384-3222B.C) in the mechanics, (Sirohi, 1991). Balance is accomplished by moving the beam through the loop of cord, which acts as the fulcrum point, until balance is obtained.

About 2000 years ago the ancient Romans developed the *steelyard.* Like the equal-arm balance, the steelyard consists of a beam supported by a fulcrum, and weight measurements are made by balancing a known weight on one side of the fulcrum against an unknown weight on the other side of the fulcrum. The Roman steelyard, in which the fulcrum is fixed so that suspended loads have a constant movement arm and are counter balance by a moveable poise, is probably of slightly less antiquity than the bismar. The principle of the Roman steelyard is applied to modern steelyard used by butchers and is incorporated in improved form in platform and weighbridge. Until the end of the eighteen century, very large steelyard was used for weighing carts. The steelyard, often as much a 20ft long, was suspended from a gantry or beam projecting over the highway and capable was of being raised or lowered by means of a block and tackle winch. The steelyard was lowered until chains suspended from the load hook could fasten to a cart from which the horse had been untarnished. The whole was then raised, slowly and laboriously, until the cart was clear off the ground. Poise was moved along the bars, until an operator who could walk along a platform below the steelyard established equipoise; innkeepers often owned these carts steelyards, (Jain, 1990).

The Turnpike Act of 1741 authorised road trustee to erect at toll gates "any cranes machine or engine which they shall judge for weighing of carts, wagon or other carriage" and charged them to levy toll according to weight and to apply revenue to the repair of roads. Although this act increased the number of cart steelyard, the inconveniences of weighing by spurred inventor help to device some laborious and expedition manner of weighing. It has been claimed for Eayre and Yeomas in 1739, they invented the platform of weighing machine, but John Wyath in 1741constructed the first compound level platform scaled and his first weighbridge was erected at the Birmingham workhouse. Next, in chronological order, came the spring balance, Richard Salter, (1760), Progenitor of the firm of George Salter and co. Ltd., of west Bromwich, is known to have been making spring in 1760 and to have made a barrel spring balance, (Sirohi, 1991).

About the year 1770, early in the nineteenth century, Augustus Siebel and Marriott H. in 1946 invented the bow spring balance. The latter form of resistant and indicator was for many years used in platform machines supplied by Henry Pooley in 1947, used in Great Britain. In the one on the left, the semi-circular charts acts a pendulum. In the one on the right the triangle members has a similar function; both include the plumb bob and cord to serve as an index, (Haslam, *et al*, 1970)

Counter scales of the Roberval type in 1906 were first made at the beginning of the nineteenth century and weighing machines of the Beranger pattern were made at about the middle of the century, (Robert, 1992). These patterns have undergone but little change construction to this day. Automatic weighers for the handling of grains were first used in Great Britain at the beginning of the twentieth century. The fundamental principle of design has been maintained, although there have been many variations to accommodate user need. Since the 1907 there has been acceleration development of semi-self-indicating and fully self-indicating weighing machine designed to reduce or obviate the tedium of handling multiplicity of weight for weighing. Self-indicating and most semi-self-indicating weighing machine afford for weighing different quantities of goods in successive operation by Grif, (Helcalfe, 1975).

Modern balances that use the same principles as the equal-arm balance and the steelyard can make very precise weight measurements. Precision balances used in scientific laboratories can measure the weight of small amounts of material down to the nearest 1 millionth of a gram (3.53 hundred millionths of an ounce). Such weighing devices are enclosed in glass or plastic to prevent wind drafts and temperature variations from affecting the measurements. Other mechanical scales in use today include pendulum scales and spring scales. In a pendulum scale, a platform is connected to a weighted pendulum. When an object is placed on the platform, the weighted pendulum swings out to the side to balance the load; a needle attached to the pendulum indicates the weight. In a spring scale, a platform is connected to a spring, which either stretches or compresses to balance a load placed on the platform. A needle whose position depends on the extent to which the spring is stretched or compressed indicates the weight of the load.

II. MATERIALS AND METHODS

Materials selection

The choice of components used for this development of 400 N spring weighing machine is based on the following factors: Efficiency of equipment, Simplicity of design and Cost. Table 1 shows the materials criteria for the selection.

Table 1: Materials Selection

S/N	Machine Part	Material	Unit	Criteria
1.	Pivot shaft	Mild steel	1	Readily weldable, low strength , high ductility, hardenable surface, good heat treatment and cold workings
2.	Helical spring	Mild steel	4	High compressive strength, good damping characteristics, high torsional strength and low tensile strength
3.	Frame	Mild steel	1	Readily weldable, low strength , high ductility, hardenable surface, good heat treatment and cold workings

4.	Load carrier	Mild steel	1	Readily weldable, low strength , high ductility, hardenable surface, good heat treatment and cold workings
5.	Rack and pinion	Mild steel		Machinable, highly ductile, good heat treatment
6.	Bushing	Mild steel	4	Machinable and good strength
7.	Spring support	Mild steel		High strength
8.	Bolt and nut	Mild steel		High strength

Design Analysis of the Spring Weighing Machine

The design analysis was determined using equation (1) to (22) and table 2 shows the calculated value of the equations.

Design Analysis for Helical Spring

$$C = \frac{D}{d} \text{(Shigley and Mischke, 2001)} \quad (1)$$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} \quad (2)$$

C = spring index

D = Mean diameter of spring, mm

d = Diameter of wire, mm

K = Wahl factor

The maximum torsional (shear) stress, σ_s due to maximum load, W to be weighed

$$\tau_s = K\frac{8WD}{\pi d^3} \text{(Shigley and Mischke, 2001)} \quad (3)$$

τ_s = maximum torsional stress, N/m^2

W = maximum load, N

The linear deflection, δ of the spring due to axial load, W

$$\delta = \frac{8WC^3 n}{Gd} \text{(Holowenko, \textit{et al}, 1983)} \quad (4)$$

W = axial load, N

δ = linear deflection, mm

G = modulus of rigidity, N/m^2

n = Number of spring coils

The spring of 20 active turns is to be used for the spring weighing machine

$$\theta = \frac{2\delta}{D} \quad (5)$$

θ = angular deflection, degree

Torque or twisting moment, T due to the axial load, W

$$T = W \times \frac{D}{2} \text{(Khurmi and Gupta, 2004)} \quad (6)$$

Energy stored, E for helical spring subjected to an axial load, W

$$E = \frac{\tau_s{}^2}{4G} \quad (7)$$

E = Energy stored, J/m^3

Design Analysis of Gear

Base on design application, a mild steel rod of 35 diameter will be suitable for the spur gear (pinion). This diameter represent Addendum circle diameter. A standard pressure angle of 20^0 for full depth involute system is used and a module, m of 1.5.

Addendum circle diameter (Outside diameter of the pinion) (D_O) = 35 mm

Addendum = 1m = $1 \times 1.5 = 1.5$ mm

Dedendum = 1.25m = $1.25 \times 1.5 = 1.875$ mm

Tooth thickness = 1.5708m = $1.5708 \times 1.5 = 2.3562$ mm

Working depth = 2m = $2 \times 1.5 = 3$ mm

Total depth (Addendum + Dedendum) = 2.25m = $2.25 \times 1.5 = 3.375$ mm

Clearance = 0.25m = $0.25 \times 1.5 = 0.375$ mm

Filet radius at root = 0.4m = $0.4 \times 1.5 = 0.6$ mm

Pitch circle diameter of the pinion (D_P) = $D_O - 2 \times$ Addendum = $35 - 2 \times 1.5 = 32$ mm

Circular pitch, $P_C = \pi m = 1.5\pi = 4.712$ mm

Pressure angle = $\emptyset = 20^0$

Determination of number of teeth of the pinion, T_P

$$T_P = \frac{D_P}{m} \text{(Khurmi and Gupta, 2004)} \quad (8)$$

For Pinion: Base circle radius, $R_b = r_P \cos\emptyset = \frac{D_P}{2}\cos\emptyset$

Determination of number of teeth of the rack, T_R

The transmission ratio between the pinion and the rack is 2: 1

$$T_R = \frac{D_R}{m} = 2\,T_P \quad (9)$$

For Rack: Base circle radius, $R_b = r_R \cos\emptyset = \frac{D_R}{2}\cos\emptyset$

Design Analysis of Shaft for Pinion

Weight of the pinion, W_P (N)

$$W_P = 0.00118 T_P b m^2 \quad (10)$$

b = face width of the gear teeth, mm

$$y = 0.154 - \frac{0.912}{T_P} \text{(for } 20^0 \text{ full depth involute system)} \quad (11)$$

$y =$ tooth form factor (for 20^0 full depth involute system)

$$\sigma_w = \sigma_a \times C_V \quad (12)$$

σ_a = Allowable static stress for steel untreated $= 140\ N/mm^2$

C_V = Velocity factor

V = Pitch line velocity

$$C_V = \frac{3}{3+V} \quad (13)$$

$$W_T = \sigma_w b\ P_C\ y \text{ (Lewis equation)} \quad (14)$$

W_T = Tangential load(N)

Using equation of motion to determine the pitch line velocity, V

$$V^2 = U^2 + 2aS \quad (15)$$

S = tooth space of the pinion which is the distance moved by the rack

a = acceleration due to gravity $= 9.81\ m/s^2$

$W_N = W_T / \cos\emptyset$ (16)

W_N =Normal load

Load on the bearing of the pinion shaft. It is the radial load, W_r

$W_r = W_N \sin\emptyset$ (17)

The resultant load, W_R (N)

$W_R = \sqrt{[(W_N)^2 + (W_P)^2] + 2 \times W_N \times W_P \times (\cos 20^o)}$ (18)

Bending moment on the shaft due to the resultant load, M_b (N)

$M_b = W_R \times$ distance between the centre of pinion and the centre of bearing

Torsional moment on the shaft due to tangential load, M_t (N)

$M_b = W_R \times S_P$ (19)

S_P = distance between the centre of pinion and the centre of bearing

$M_t = W_T \times D_P/2$ (20)

Equivalent Twisting moment, T_e

$T_e = \sqrt{[(M_b)^2 + (M_t)^2]}$ (Khurmi and Gupta, 2004) (21)

$d^3 = (16\ T_e) / \pi \times \tau$ (22)

d = shaft diameter, mm

τ = shear stress of the shaft material without key = 56 N/mm^2

Table 2: Design Analysis

S/N	Equations	Equations No.	Results
1	$C = \frac{D}{d}$	1	10
2	$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$	2	1.145
3	$\tau_s = K\frac{8WD}{\pi d^3}$	3	1.3 GN/m^2
4	$\delta = \frac{8WC^3n}{Gd}$	4	0.3 m
5	$\theta = \frac{2\delta}{D}$	5	20^o
6	$T = W \times \frac{D}{2}$	6	6 Nm
7	$E = \frac{\tau_s^2}{4G}$	7	5.3 MJ/m^3
8	$T_P = \frac{D_P}{m}$	8	21 teeth
9	$T_R = \frac{D_R}{m} = 2\ T_P$	9	42 teeth
10	$W_P = 0.00118 T_P b m^2$	10	0.8 N
11	$y = 0.154 - \frac{0.912}{T_P}$ (for 20^0 full depth involute system)	11	0.11
12	$\sigma_w = \sigma_a \times C_V$	12	130 MN/m^2
13	$C_V = \frac{3}{3+V}$	13	0.93
14	$W_T = \sigma_w b\ P_C\ y$ (Lewis equation)	14	1016 N
15	$V^2 = U^2 + 2aS$	15	0.22 m/s
16	WN =WT / Cos∅	16	1081 N
17	Wr= WN sin∅	17	370 N
18	WR=√ [(WN) 2 + (WP) 2] + 2 × WN × WP × (Cos20°)	18	1082 N
19	Mb=WR × SP	19	40 Nm
20	Mt = WT × DP/2	20	16 Nm
21	Te = √ [(Mb) 2+ (Mt) 2]	21	43 Nm
22	d3= (16 Te) /π x τ	22	15 mm

Calibration of Scale

The materials needed for the calibration of a new scale of mechanical weighing machine as follows:

Standard weight of 1 kg to 40 kg were needed and Protractor marking tools

The following procedures were followed in calibrating the scale of simple weighing machine such as:

i. Take where the deflector rested as reference point without load.
ii. Mark that point as zero.

iii. Then add standard weight of 1kg, the deflector will move, mark where the deflector stop.

iv. Repeat the procedure above for other different weight until 40 kg weight is placed and also mark at that point on the scale.

Find the degree of deflection in between each weight increases from 1 to 10 kg

35 kg gives 360^0 (1 revolution deflection)

1 kg = $\frac{360}{35} = 10.3^0$deflection

Therefore 40 kg gives 1 revolution and 50^0 deflection (The scale will look like a dial indicator scale)

Since 1 kg = 1000 g

For 1^0deflection, we have $\frac{1000g}{10.3} = 97g$ approximately 100 g

Therefore, it will take as from 100 g weight of load for the deflection to move. When it is less than 100 g weight of load there will be no deflection.

III. RESULTS AND DISCUSSION

Testing the mechanical weighing machine developed in order to verify its overall performance which is the load carrying capacity of the machine. Materials were weighed for the testing with different loads placed on the weighing machine. The readings taken were given in Table 3 and Fig. 1 shows the variation of the test of the machine. Therefore, the efficiency of the machine was determined using equation (23).

Table 3: Testing Data

Test	Measured Valued (kg)
1	36.5
2	37.1
3	36.8
4	37.5

Average measured reading (kg)

$$= \frac{36.5 + 37.1 + 36.8 + 37.5}{4} = \frac{147.9}{4} = 37.0 \text{ kg}$$

$$\text{Efficiency} = \frac{\text{Average measured value}}{\text{Actual capacity of the mchine}} \times 100 \quad (23)$$

$$\text{Efficiency} = \frac{37}{40} \times 100$$

Efficiency = 93 %

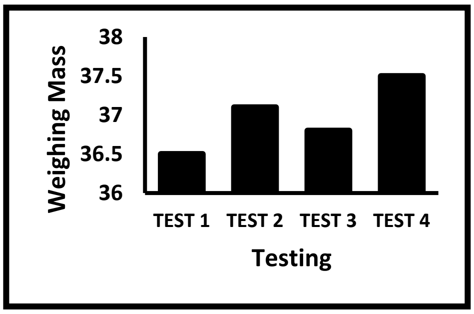

Fig. 1: Variation of measured Value

IV. CONCLUSION

The mechanical spring weighing machine developed could meet the requirements of the user being that it is simple, strong, durable, portable and affordable. It will be very useful for the weighing of bulky materials or packed piece in the laboratory. The machine parts can be obtained locally and it can work for longer period of time if the mechanism is well maintained.

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APPENDICES

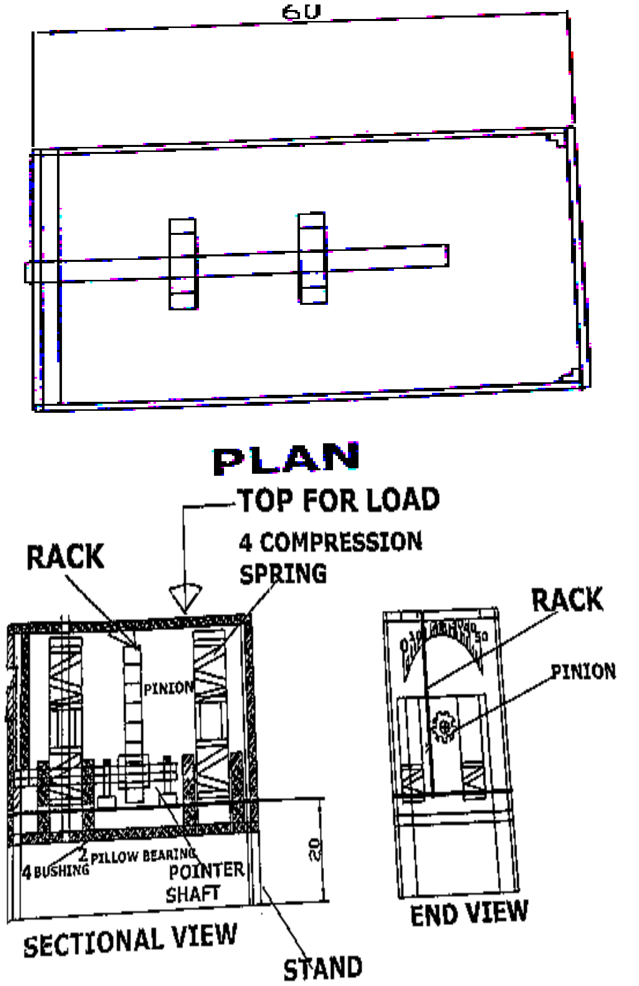

Fig. 2: Orthographic Projection of the Spring Weighing Machine

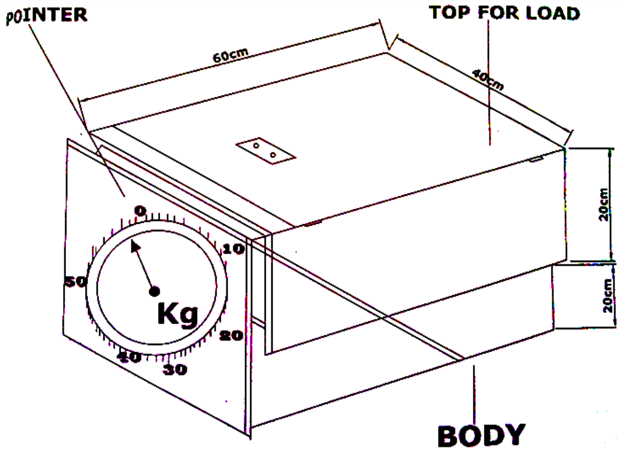

Fig. 3: Isometric Projection of the Spring Weighing Machine.

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Plate 1: Fabrication Phase 1

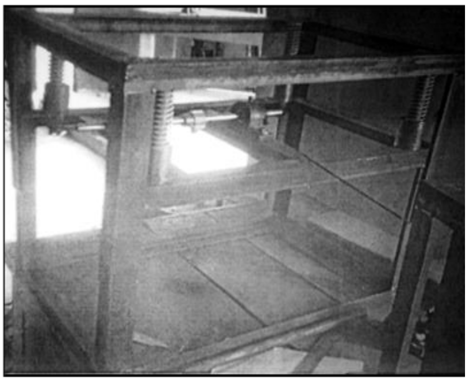

Plate 2: Fabrication Phase 2

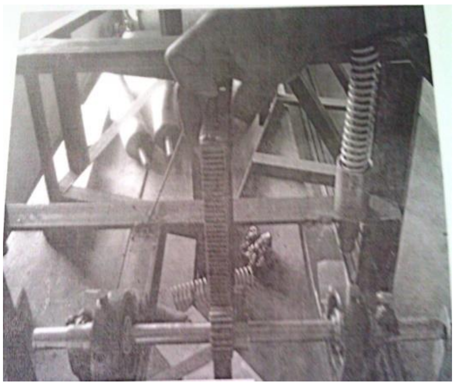

Plate 3: Fabrication Phase 3

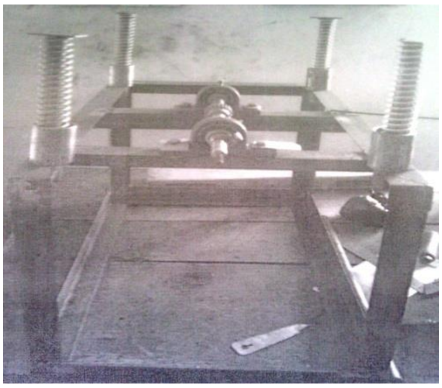

Plate 4: Fabrication Phase 4

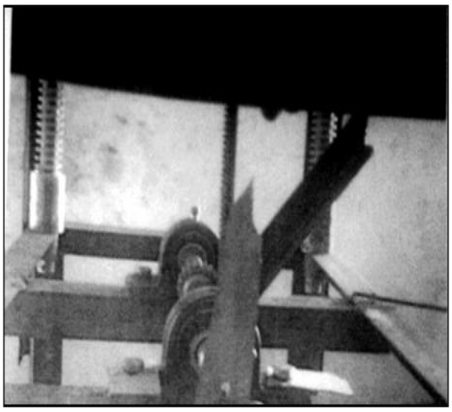

Plate 5: Fabrication Phase 5

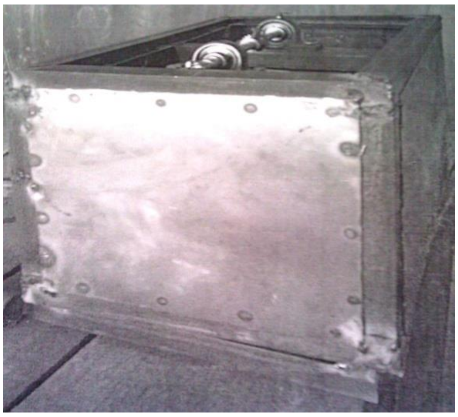

Plate 6: Fabrication Phase 6

Plate 7: Assembly

Plate 8: Spring Weighing Machine