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Design and Simulation Study of Automatic Dead Weight Rotator for Dead Weight Testers

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It is well known that the Dead Weight Testers (DWTs) or Pressure Balances (PBs) are among the finest instruments for accurate high-pressure measurement, with low uncertainties in the pressure range of a few KPa to a few GPa. During the measurement process, either the piston or the cylinder of DWTs is made to rotate either manually or through a motor to minimise the frictional forces and to distribute the lubricating fluid in the crevice of the piston and cylinder (P-C) assembly. The majority of industrial DWTs are not equipped with a motor, and hence, the weights on the piston are rotated manually, which possibly contributes to the additional tangential forces. Also, by using manual rotation, the constant rpm of the piston is very difficult to maintain. To address these issues, the authors have proposed a novel design of a mechanical instrument designated as a dead weight rotator (DWR), which is capable of rotating the weights at constant rpm and can be accommodated in any type of DWT. The design is targeted for ~30 rpm rotation of the piston and for a dead weight of up to 100kg. In addition, simulation studies based on finite element analysis are carried out on the developed design to check the effects of the operation of DWR on the dead weights. The simulation results, including stress, strain, deformation analysis, and various design aspects of the DWR, along with their limitations and future scope, are discussed in detail. Ongoing work focuses on the fabrication and experimental design, which will be reported in due course.

Keywords: Dead weights rotator, Dead weights, Pressure balances, Finite element analysis, Simulation

Introduction

Dead Weight Testers (DWTs) are mechanical devices deployed for precision pressure measurements and are also known as Pressure Balances (PBs) or Piston Gauges. The DWTs consist of an assembly of the Piston and Cylinder (P-C) to deliver highly accurate results with minimum possible error and low uncertainties in the measurement. The traceable dead weights in DWTs are used to apply an opposite force on the fluid to achieve equilibrium with the generated pressure. Due to their ability to measure pressure with the best accuracy, DWTs are designated as the primary/reference pressure standards in many National Metrology Institutes (NMIs) across the globe.[1–5] These provide traceability by calibrating various pressure-measuring instruments, e.g., piston gauges, digital transducers, master dial gauges, etc., which in turn are further used for numerous applications ranging from day-to-day life to sophisticated industrial processes.[6,7] Over the decades, continuous advancements in materials, design, and manufacturing have further enhanced the performance of DWTs, enabling extended pressure ranges, improved stability, and reduced sensitivity to environmental factors. Modern DWTs are offering automation, improved repeatability, and ease of operation. Their robustness and long-term reliability make them indispensable in calibration laboratories, research facilities, and industries where maintaining traceability to international pressure standards is critical.[8,9]

The main component of DWT is a closely fitted P-C assembly. The piston and the cylinder have a very small clearance (0.5–1 μm) between them with a fine surface finish. This P-C assembly is loaded with known traceable dead weights to achieve the state of equilibrium with the inlet pressure, which is applied at the bottom of the piston through gas or liquid media. Since there is no physical contact between the piston and the cylinder walls, it is essential to make the central axis of the cylinder and the piston co-linear, using the centrifugal force generated by the rotation of the

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piston.[10,11] The P-C assembly of DWT is rotated about its central axis to minimise the contribution due to friction between the piston and the cylinder and for even distribution of lubrication fluid. This rotation is either hand or motor-driven. One such DWT, designed and manufactured with an integrated motor for enhanced functionality, is shown in Fig. 1.

However, most industrial use DWTs are not manufactured with an inbuilt driving motor and are usually hand-driven, which may cause non-uniform rotation and lead to jerking of the P-C assembly [10], leading to inaccurate pressure measurement if the rotation is not uniform or if tangential forces are created due to manual rotation. Hence, in this study, an attempt has been made to devise an in-house and cost-effective mechanical instrument that can rotate dead weights on the DWT at the desired rpm.

As mentioned, during the process of measuring pressure using a DWT, a state of equilibrium must be maintained between the line pressure (generated pressure) and the required dead weights loaded over the piston.[1,12–16] It must be noted that the dead weights loaded on the P-C assembly also rotate about their axis by being loaded onto the piston. The significance of rotating the weights is again to reduce the frictional forces generated and to ensure smooth flow of the lubricating fluid in the piston cylinder clearance. The DWTs equipped with an inbuilt motor rotate the dead weights generally through a pulley and an O-shaped belt mechanism, as shown in Fig. 1. However, for most industrial-use DWTs, the weights are generally rotated manually. As mentioned, this manual rotation may give rise to a few problems, as listed below:

- The rpm may not be the same for each data point of each cycle, when a number of measurements are made.
- A tangential force could arise from the application of a rotating force by hand, which may cause a misalignment of the P-C assembly, leading to a possible disparity in the pressure measurement.
- With manual rotation, an unintentional additional force may also be generated, influencing the pressure readings. This effect is considered an unquantifiable factor in pressure measurement.
- Since this rotating force is not constant and changes with each application of manual force to the weights, it can contribute to an increase in the level of uncertainty of the measurement by a magnitude that is very difficult to estimate.

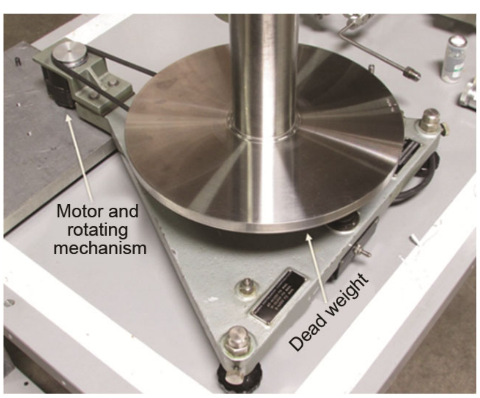

Fig. 1 — A typical DWT equipped with an inbuilt motor for rotation of the dead weight

In the present work, the factors discussed above are taken into consideration, and a novel design of a mechanical device has been proposed that can rotate the dead weights loaded on the DWT during pressure measurement and calibration. The ultimate goal of this dead weight rotator would be to rotate the dead weights loaded on the piston at a desired constant rate and disengage from the system so as not to create unwanted forces onto the experimental setup. The following sections describe the design and feasibility analysis of the various components of the proposed mechanical device in detail.

Design of a Dead Weight Rotator

This proposed Dead Weight Rotator (DWR) is a separate stand-alone device that can be associated with various DWTs, unlike certain DWTs that have an integrated motor system to rotate the P-C assembly. As mentioned, this mechanical instrument must be designed to rotate the dead weights without interfering with the pressure measurement. DWR's main function is to turn the dead weights at a pre-determined speed (e.g., usually between 20 and 30 revolutions per minute) and has been designed to be utilised with DWTs of various types and sizes, promoting economic efficiency.

The modus operandi of this DWR is proposed to include an assembly of mechanical arms with rollers that can come into contact with the stacked dead weights, rotate them to the desired rpm, and then disengage from the dead weights in order to prevent interference with the operation of the DWT or the measurement values. In a piston-cylinder assembly that is lubricated with either gas or oil, this initial operation results in a smooth rotation since a frictionless system can rotate for a sufficient time for recording measurements.

Dead Weight Rotator Assembly

The designed DWR is an assembly of a few sub-assemblies, which include the lead screw assembly, climbing box assembly, housing assembly, arm engaging assembly, and live roller assembly. Each of these sub-assemblies has specified functions and has different individual parts and different mechanisms. The working of these individual assemblies is discussed in the subsequent sections.

Lead Screw Assembly

The first and foremost requirement for the design of the DWR was a solid base on which all the sub-assemblies were supported and mounted. This requirement was met by the lead screw assembly, which consists of two different components, viz., the base plate and the lead screw. This lead screw is attached to the base plate and plays a key role in the working of this instrument. As the name suggests, this base plate, made of mild steel, serves as a base, on which the whole instrument stands. It supports the whole system and the other sub-assemblies. This base plate accommodates the weight of the assembly and, therefore, needed to be designed so as to balance the complete assembly during functioning when the assembly moves up and down, as well as when the arms move horizontally to engage with the dead weights and also while rotating the dead weights. All these operations may lead to imbalance, and therefore, the job of the base plate is to keep the centre of gravity of the complete instrument within limits. Since the base plate plays such a crucial role, its shape and size were calculated diligently and the optimal size turned out to be a square plate of 200×200 mm size with a thickness of 12 mm.

The next component of the lead screw assembly is the lead screw, which serves as a vertical path along which the climbing box assembly can move; it also serves as a backbone of the complete instrument and helps in balancing the instrument. The lead screw has a pitch of 3.175 mm, so that the climbing box assembly can use it to move up and down along the lead screw with the help of gears. The 3D model of the base plate and lead screw of the DWR is shown in Fig. 2.

Climbing Box Assembly

The commercially available DWTs can be of different types and sizes depending upon the working range of pressure and, likewise, the stacking of the weights can be shorter or taller in height depending on the magnitude of the pressure to be measured, as well as the denomination of the dead weights.[17,18] Since the stacking of the dead weights can be of varied height, the DWR cannot be made of a fixed height. Hence, the next requirement of the design is that of height adjustability of the DWR so that it can cope with the constantly varying height of the stacked dead weights. The requirement for height adjustment is fulfilled with the help of the climbing box assembly.

The climbing box assembly, as shown in Fig. 3, gives freedom to adjust the height of the apparatus according to the dynamic experimental requirement and is capable of engaging the apparatus at any desirable height. The maximum and the minimum usable height of the apparatus was decided through a survey of the height of different types of commercially available DWTs at different applied pressures. After careful examination and analysis, the required maximum height of the DWR was considered to be 500 mm, which broadly covers the whole range of commercially available DWTs.

This climbing box assembly consists of a few mechanical components working in harmony to deliver the specific function of height adjustment. The assembly contains a knob capable of clockwise and anticlockwise rotation, which results in an increase or decrease in the height of the apparatus, respectively. This knob is connected to a worm gear through a solid shaft. As the knob is turned clockwise or anticlockwise, the worm gear also turns clockwise and anticlockwise. The worm gear is further

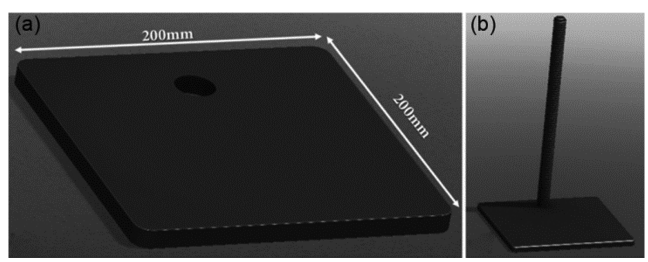

Fig. 2 — 3D model of the designed dead weight rotator: (a) base plate and (b) lead screw

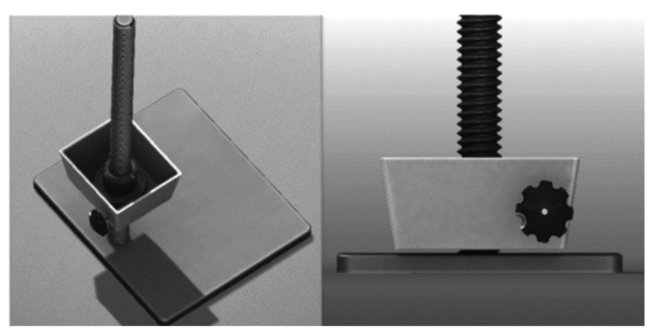

Fig. 3 — 3D model of the climbing box assembly

interlocked with a spur gear, which is further meshed with the lead screw threads. Therefore, with the rotation of the knob on the climbing box, the worm gear rotates, which in turn drives the spur gear, leading to the ascent or descent of the lead screw, depending on whether the rotation is clockwise or counter clockwise.

The pitch of the lead screw is kept small by design so that the user can have a more controlled and sensitive height adjustment function. Using this mechanism, the DWR could work with different heights of DWTs.

Arm Engaging Assembly

It is also noted that in various types of DWTs, not only the height of the dead weight stacking, but also the diameter of the weights can be different. The dead weights are usually loaded on a weight carrier bell, which is placed over the piston-cylinder assembly to balance the pressure exerted at the bottom of the piston. Typically, the dead weights usually have a disc shape with a circular cavity in the centre. The circular cavity in the centre of the disc is of significance because the disc is loaded over the piston, and the centre of gravity of the weights aligns with the centre of gravity of the piston and the bell. The P-C assembly is a sensitive, accurate, and very fine instrument, which must be handled with diligence. To enable the generation of high pressures, the diameter of the piston can be very small, i.e., a few millimetres only, and hence, the loading of dead weights, which can have diameters in the range of a few centimetres to tens of centimetres, needs to be handled with caution so as not to damage the piston.

For example, a certain weight disc available at CSIR-NPL has a diameter of around 320 mm with a weight of about 5 kg. Directly loading a weight disc of such a diameter and weight over a piston of a small size is not possible because it may damage the piston and also ruin its alignment. A bell is an accessory devised to cater to this problem, which makes it possible to load weight discs over the piston. Different types of pistons and bells are available and are used depending on the measuring pressure range.

As discussed, since the diameter of the weight stacking can be different depending upon the magnitude of the pressure we wish to measure, the DWR must be able to cater to these variations in the diameter of the weight stacking and must be able to engage at any diameter. To fulfil this requirement, an arm-engaging assembly was proposed and designed. The arm-engaging assembly uses two arms that employ a mechanical system to engage and grab the weight stacking for rotation.

As shown in Fig. 4, the arm-engaging assembly houses multiple components that work together to produce the required functions. The fundamental idea of rotating the dead weight stacking was to use a roller of such a material that would not damage the weight discs. Hence, the rollers are Teflon-based and can be used for engaging directly with the dead weights to rotate them. Further, the rollers need to be in good contact with the weight discs to establish a no-slip condition, and also be able to induce the required rotation. For this purpose, two rollers have been employed to grasp the weight stacking at diametrically opposite ends of the weight stack. These two rollers are designed to ensure a firm grip on the weight stacking and maintain the instrument's balance. The significance of grabbing weight stacking at the far end of the diameter is to cancel out the possibility of the occurrence of a tangential force.

Considering the above-mentioned requirements, two arms were designed as shown in Fig. 4 and used in a scissor-like arrangement to act as robotic arms to hold the dead weights across their diameter. These arms were coupled to a motor and an appropriate gear. The motor controls and operates the arms at the command of the user. This arm-engaging mechanism requires a reversible motor to enable rotation in both clockwise and anti-clockwise directions.

These arms were designed with careful consideration of the forces that these arms were required to apply on the dead weight stacking. Requisite calculations were carried out to find the force acting on the weight stacking due to the action of the arms, and the specifications of the primary motor were chosen by careful survey and calculations. The force acting on the dead weight stacking of the DWT through the application of the DWR can be determined by considering the torque generated by the

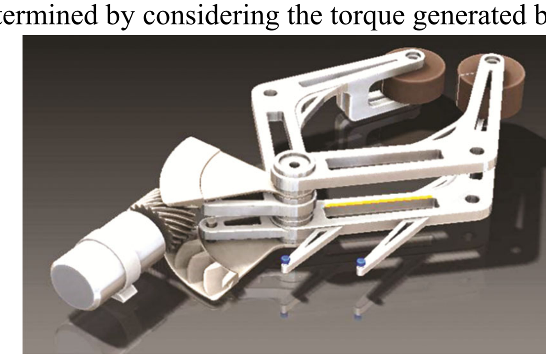

Fig. 4 — Arm engaging assembly

motor and relating that torque to the force transferred to the dead weight stacking by the rollers. Since the both arms have identical geometry, the force transferred by both arms is the same, and the calculations performed for any one arm will apply to both arms. The tangential and axial forces are illustrated in Fig. 5. The estimations carried out are discussed in a subsequent section.

Live Roller Assembly

As discussed, it is important to devise the DWR in such a manner that it does not harm or disturb the optimum operation of DWTs in any possible way. Hence, it was considered pertinent to equip the DWR with the live roller approach. A live roller is a roller that can rotate on its axis, and in this particular scenario, we have devised a way of coupling the live roller with the dead weight stacking. The reason for using a live roller coupled with the dead weight stacking is to ensure that the DWT remains under balance. This live roller in the DWR engages and disengages with care, ease, and diligence. The speed at which the arms and roller engage and disengage with the DWTs is determined by the motor driving the arms and the number of teeth in the gears that help in the transmission of motion from the motor to the DWR arms. Keeping the sensitivity of the DWT in mind and the requirement of ease with which the DWR must engage with the dead weight stacking, gears with a high number of teeth were equipped to perform the task. The greater the number of teeth in the gears, the more time it will take to complete its revolution.

To make the process of grasping of the dead weight stacking slow and steady, the helical gear coupled with the primary motor (the motor that drives the arms) is small in comparison to the bevel gears that are coupled with the arms and are driven by the helical gear coupled with the primary motor as shown in Fig. 6. Once the arms establish a firm contact between the roller and the dead weight stacking, the live roller assembly comes into play. The assembly,

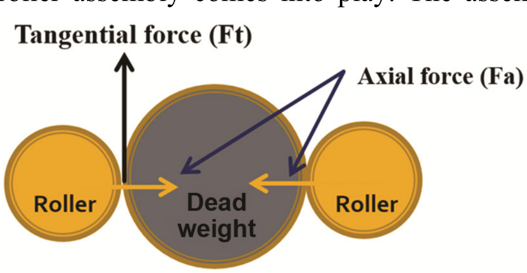

Fig. 5 — Force diagram

as shown in Fig. 7, consists of a number of components, namely roller bushings, Teflon sleeves, a belt, a pulley, and a secondary motor.

The roller bushings in the live roller assembly are coupled to the belt. This roller bushing is also coupled to the arms using a simple nut, but the roller is allowed to rotate about its axis. The roller also carries a groove to enable the fitting of the belt. The bushing is covered with a Teflon sleeve, which is an important detail in the process of rotating the dead weight stacking, as it needs to serve as a non-detrimental and smooth interface that does not damage the weight disc in any way. Therefore, the sleeve was chosen to be made of the material that serves the purpose and is easily available, considering the present requirements. Thus, Teflon proved to be a good material for this purpose. Consequently, the brass bushing rotates the sleeve, which in turn rotates with the roller, maintaining good contact with the dead weights.

Once firm contact with the dead weights is achieved, all that is left is to transmit the rotation from the motor to the weight stacking. To fulfil this functional requirement, a belt is coupled between the pulley of the secondary motor and the brass bushing

Fig. 6 — Primary motor with helical gears

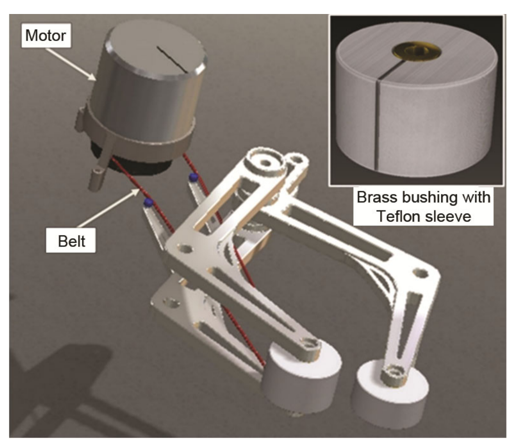

Fig. 7 — Live roller assembly

at the arms. A circular belt of a defined radius is expected to perform excellently in this particular scenario. The belt can be of the same material as an O-ring, i.e., made up of neoprene. This belt must remain tight at all positions of the arms, whether at the closest or the farthest. Since the arms are allowed to pivot about a fixed point, the rollers also move with the arms, towards and away from the motor when the arms converge and diverge. Due to this movement, the belt is unable to remain tight throughout the motion of the arms and rollers. As the arms open or diverge, the roller bushing comes close to the pulley and the secondary motor. On the other hand, when the arms close or converge, the roller bushing moves away from the pulley, and the minimum length of the belt required for the operation is increased. To accommodate this inconsistency in the length of the belt, a set of pulleys is used in such a manner that the belt remains tight at all the positions of the arms.

The arrangement and positions (as shown in Fig. 8) of the pulleys are designed and calculated as the positions of the pulleys change with the movement of the arm and the roller across the horizontal plane. Since the rollers can be engaged at any point in the path, the pulley arrangement cannot be fixed. For this reason, the pulleys must ensure that the belt remains tight throughout the path of the roller. To make sure that happens, the pulleys themselves should move to adjust the belt at any point throughout the path of the roller. A mathematical model is prepared for the length adjustment of the belt across the pulley and the roller, and is illustrated in the following section.

Calculations of the Self-adjusting Pulleys

The total length of the belt consists of arc lengths and the straight paths; we must calculate the length of the belt in both the scenarios of open and closed arm positions. The straight paths can be added directly, but the arc lengths must be calculated first by using the arc angles and then added as lengths,

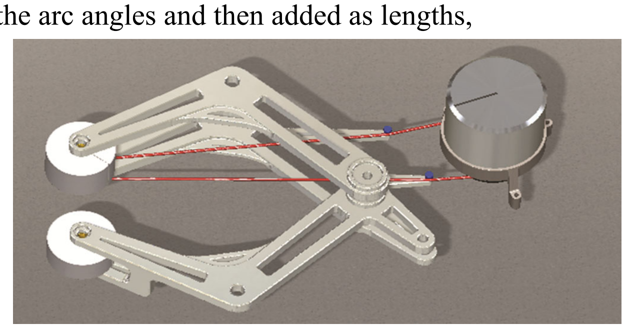

Fig. 8 — Self-adjusting pulley system

The nomenclature used for the calculation in Fig. 9, is as follows:

AL1 = Arc length associated with the belt around the driving pulley;

AL2 = Arc length associated with the brass bushing;

AL3 = Arc length associated with the pulley over the arm;

AL2 = Arc length associated with the pulley over the arm.

The first case in consideration will be the position of the roller when the roller is farthest away from the pulley. As shown in Fig. 10, the various lengths associated with various sections of the arms need to be added to find the circumference of the belt;

Now we may calculate and prove that this moving pulley mechanism can maintain the tightened belt condition. The total length of the belt consists of straight paths (S(st.)) as well as curved paths over pulleys and bushings. Adding all the straight paths, as shown in Fig. 10(a), when the arms are closed, we find the length of the straight path, which is

S(st.) = 348.03 + 311.78 + 95.79 + 67.52 (all in mm)

S(st.) = 823.12 mm

Now we calculate the length of the curved paths using,

θ = (arc length)/radius

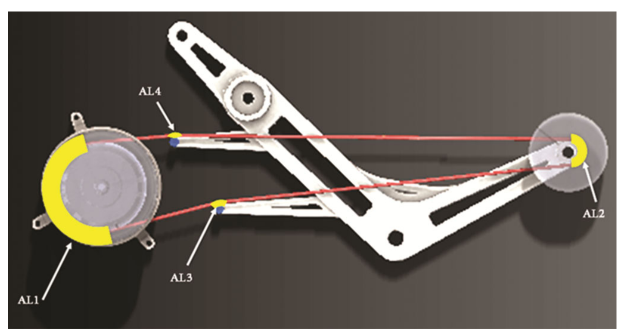

Fig. 9 — Nomenclature used for calculations; the yellow-highlighted lengths show the various effective lengths engaged with the pulleys

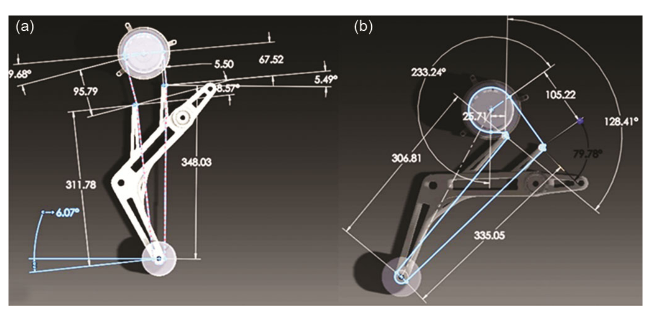

Fig. 10 — Different lengths of belt when arms are in: (a) closed and (b) open positions

Using the relation mentioned above to calculate the lengths of arcs, we obtain the following results:

Around the motor pulley;

$(180°+9.68°) \times \pi/180 = (\text{arc length (AL1)})/40$

Hence, AL1 = 132.35 mm

Around the brass bushing;

$(180°-6.07°) \times \pi/180 = (\text{arc length (AL2)})/11.50$

And, AL2 = 34.89 mm

Around the self-adjusting pulleys;

$(8.57°) \times \pi/180 = (\text{arc length (AL3)})/5.50$

AL3 = 0.82 mm

$(5.49°) \times \pi/180 = (\text{arc length (AL3)})/5.50$

AL4 = 0.52 mm

The addition of the above-estimated lengths yields the longest required length of the belt, TL_{far}, which comes to;

TL_{far} = S(st.) +AL1+AL2+AL3+AL4

TL_{far} = (823.12+132.35+34.89+0.82+0.52) mm

TL_{far} = 991.7 mm

Therefore, 991.7 mm is the maximum length required to operate the live roller,

Now we will calculate the length adjusted by the pulleys when the roller is closest to the pulley; in this case, the pulleys move with the arms, forcing the belt to take a longer path, hence keeping it tight and engaged.

Again, referring to Fig. 10(b), when the arms are open, we will first add all the lengths of the straight paths, then calculate arc lengths, and add all the resulting lengths to determine the total length.

In order for these self-adjusting pulleys to work, their total length must be equal to the total length of the previous calculation.

Adding all the straight paths as shown in Fig. 9, we get S(st.) = 773.79 mm

Around the motor pulley;

$(233.24°) \times \pi/180 = (\text{arc length (AL1)})/40$

AL1=162.74 mm

Around the brass bushing;

$(173.25°) \times \pi/180 = (\text{arc length (AL2)})/11.50$

AL2 = 34.75 mm

And around the self-adjusting pulleys;

$(79.78°) \times \pi/180 = (\text{arc length (AL3)})/5.50$

AL3 = 7.65 mm

$(128.4°) \times \pi/180 = (\text{arc length (AL3)})/5.50$

AL4 = 12.31 mm

Now, adding all for the total length of the belt;

TL_{far} = S(st.) + AL1 + AL2 + AL3 + AL4

TL_{far} = (773.79 + 162.74 + 34.75 + 7.65 + 12.31) mm

TL_{far} = 991.24 mm

Therefore, according to the mathematical model presented above, it is possible to adjust the length of the belt with ease by introducing 2 self-adjusting pulleys that move along with the arms of the rotator, thus ensuring that the belt does not suffer slack with the movement of the arms around weights of various diameters.

With the above design considerations, most of the requirements and targets could be achieved as planned, which realize the following;

- Height adjustment;
- Arm engaging mechanism;
- Rotation through contact.

With these requirements fulfilled enabling the establishment of transmission of motion from the secondary motor to the dead weight stacking, the next step is to ensure that the dead weight stacking rotates at a specific rpm, for which we need to calculate the out-put rpm of the dead weight stacking by taking the diameters of pulleys, roller bushing and the dead weights into considerations and calculating the output rpm of the deadweight stacking.

Calculations of the rpm of the Dead Weight

The motor employed in the DWR has an output of about 30 rpm, but it can be variable according to specific speed (N). The diameters of the motor pulley (Dp) and the roller's brass bushing (DB) are estimated to be 80 mm and 20 mm, respectively, so that the output rpm of the dead weights is optimum. Hence, the ratio of the diameter of the pulley and the roller's brass bushing,

Dp/DB = 80/20 = 4

Therefore, the bushing completes 4 revolutions while the pulley completes only 1 revolution.

Rpm of bushing (RB) = N × 4 = m rpm

Since the roller is rotating at an rpm of 30,

Rpm of bushing (RB) = 30 × 4 = 120 rpm

The ratio of the diameter of the deadweight DDW, and the diameter of the roller DR, is

k =DDW/DR

Now, for a typical case when the diameter of dead weights (typically a 10 kg disc) is 300 mm and the diameter of the roller is 70 mm, the ratio of the diameter of dead weights to that of the roller becomes,

DDW/DR = 300/70 = 4.28

Then the revolution of any dead weight can be calculated with

Rpm of dead weight (RDW) = m/k

For instance, the roller completes 4.28 revolutions with a 300 mm disc diameter when the dead weights complete only 1 revolution, thus;

Rpm of dead weight (RDW) = m/k = 120/4.28 = 120/4.28 = 28.03 rpm

The calculations shown above validate mathematically that the DWR can be used with a DWT to generate the desired results without leading the reading astray.

Simulation Analysis

Apart from efficient mechanical design, it is important to ensure that the proposed device does not affect the DWTs in any way, especially in terms of causing undesirable damages, distortions or stresses which impact its functioning. Therefore, during the development of the DWR, finite element analysis was carried out to simulate the effect of the DWR acting on the weight discs to investigate whether the force acting on the dead weight stacking affects the DWTs. As listed below, a few assumptions and objectives are required to carry out the simulation to determine the desired results. These assumptions were taken as our boundary conditions, and the objectives became the expected results.

Assumptions

- No slip condition between the roller and the dead weights;
- No disturbance due to arm movement to the dead weights;
- The entire torque is transferred to the roller and dead weights through the belt drive;
- Maintains proper gear ratios;
- For a 30 rpm speed, motor torque is 2–3 Nm required;
- Material should be homogeneous and isotropic.

Objectives

- Need to maintain ~30 rpm;
- Design for a minimum dead weight of 1 kg to a maximum of 100 kg;
- Design for dead weight diameter varying from 80 mm to 300 mm;
- Motorised engagement and disengagement of arms;
- Manual mechanism to increase and decrease the height of the system;
- Motorised arrangements for rotational motion transfer to the dead weights.

CAD Modeling

A CAD model of a weight disc was made in Solid Works software, using the dimensions of a 1 kg weight disc available at CSIR-NPL, with the two rollers engaged. This model was imported into Ansys (Finite Element Simulation Package) for simulation purposes.[19,20] The model is then meshed, i.e., broken into finite elements, and the boundary conditions, as mentioned above, were applied. The CAD model of the single-weight and roller system is shown in Fig. 11. An axial force due to the engagement of the roller and dead weight would be cancelled out by the double arm mechanism that applies the same force from opposite directions

Meshing and Analysis

The standard meshing of the model was carried out in Ansys DesignModeller.[21–24] The meshed model of the weight disc that would be subjected to loads and forces is shown in Fig. 12. The obtained results of the simulation studies are shown in Fig. 13.

The contours of equivalent stress and equivalent elastic strain obtained from simulation studies can also be seen in Fig. 13 (b) and Fig. 13 (c), respectively; the maximum elastic strain developed is obtained as 6.341×10^{-6}, and the maximum equivalent stress developed in the disc is 1.22 MPa. After applying the boundary conditions and a force of 10–15 N (which is developed due to the torque of the primary motor that is used to engage the arms and which will ensure firm and steady contact with the dead weight stacking and the Teflon roller sleeves), the total deformation contour, as shown in Fig. 13 (a) thus obtained, shows that the disc undergoes a marginal deformation around its periphery and a

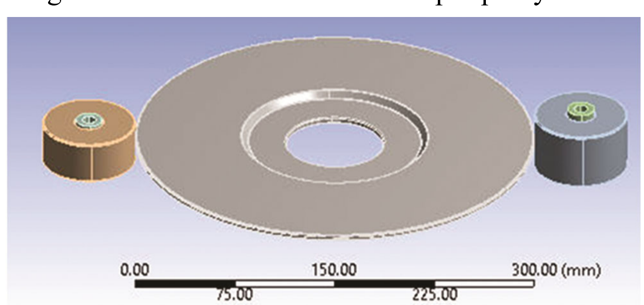

Fig. 11 — CAD model of weight disc and rollers

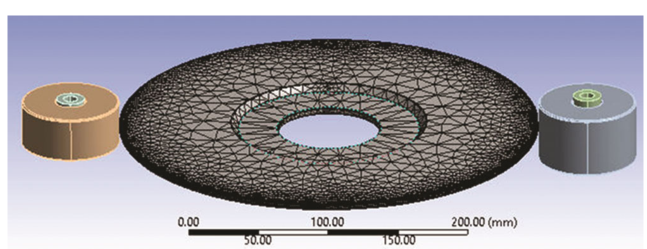

Fig. 12 — Meshed model of the weight disc

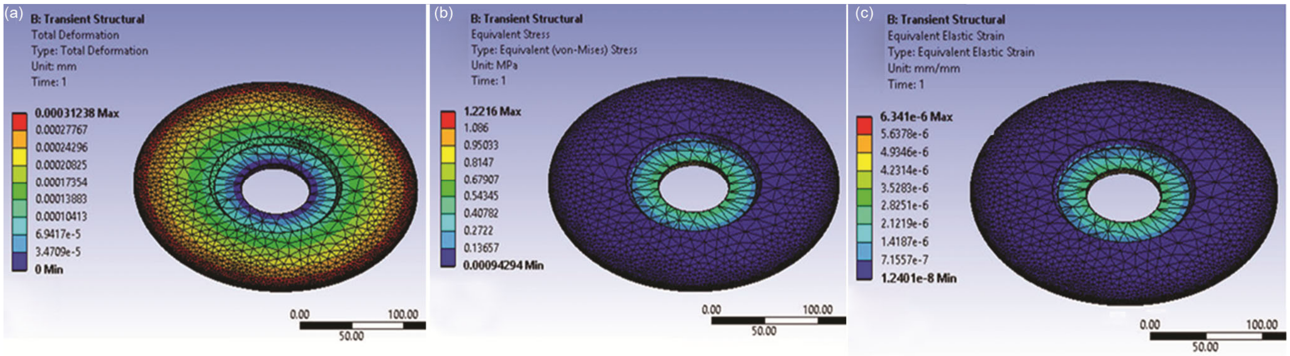

Fig. 13 — Simulation results of weight discs under the action of DWR, showing: (a) Deformation (b) Stress and (c) Strain

maximum deformation of 3.123×10^{-4} mm occurs; deformation of this level is practically negligible and the fact that the actual force acting on the weight discs would be 1/4th the force used for this finite element analysis, considering the factor of safety. The values of deformation, stress, and strain obtained from the simulation indicate that the material of the dead weights will not be damaged/hampered by the use of DWR.

Future Scope

The following is the future plan of the study;

- Using the proposed design of DWR, an improved version can be fabricated and tested for various DWTs;
- Further, since it is a mechanical instrument, it requires manual handling to operate, which may lead to the possibility of contamination as well as the generation of unwanted forces. Hence, this DWR has the potential to be made semi-automatic by the incorporation of various sensors, actuators, limit switches, etc.;
- The height adjustment mechanism is also manual in the presented model. This can be improvised into an electric height adjustment mechanism by the introduction of an electrical motor to drive the mechanism through a switch mechanism.
- The DWR can be equipped with a tachometer that analyses the dead weights' spin, and the DWR can automatically disengage when the dead weights reach a desired rpm.

Conclusions

In the present work, a dead weight rotator was conceptualised and designed to enable uniform rotation of the dead weights in a dead weight tester for pressure measurements. From the design, analysis, and studies carried out in the work, the following major conclusions are drawn;

- The proposed DWR can be a very useful and necessary accessory for eliminating manual rotation of DWTs, which are widely used in pressure measurement industries.
- The developed idea of the DWR demonstration has considerable potential, as it helps in the improvement of measurement by eliminating the need for manual rotation.
- The wide working range of the developed DWR makes it a universal instrument since it can couple with any DWT, which makes it economical. The DWR will ensure better precision every time, which is not achievable through manual rotation of dead weights.
- The DWR is safe to use with the DWTs since the finite element analysis carried out on the system demonstrates that the DWR does not cause any damage to the rotating weights.

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Data Availability Statement

No data has been used.

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Conflicts of Interest

No conflicts of interest.

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