Upgrading Manual Mass Comparator by Developing of an Automated Rotary Plate Multi-Position Weighing System

Argielou Flores[1], Kiveen Suycano[1], Jessie Yap[1], Jheison Corpus[2], Willard German[2], Patrick Karlvin Pimentel[2], Jomari Madlangbayan[2], Janelle Caringal[2]

[1] *Department of Science and Technology, Industrial Technology Development Institute (DOST-ITDI), National Metrology Laboratory of the Philippines, Bicutan, Taguig City, Philippines, metrology@itdi.dost.gov.ph*
[2]*Technological University of the Philippines – Manila, Manila City, Philippines, mechanical@tup.edu.ph*

Abstract – **Calibration of mass standards using manual mass comparators requires the repetitive loading and unloading of masses. The routine heavy-lifting could pose a threat to the integrity of the mass comparator and musculoskeletal health of the personnel. This study developed an automated rotary plate that served as an accessory for existing manual comparators in the laboratory. It is programmed to mimic the calibration process by alternately conveying the reference and test mass standards to and from the comparator. The results showed that the new calibration system can produce repeatability results that is up to 75% better than manufacturer's declaration and 18% better than manual calibration.**

This demonstrates that the integration of the system enhances the repeatability of the manual mass comparators. This implies that the system can potentially be used to calibrate mass standards of even higher accuracy class than its intended application in the laboratory.

I.   INTRODUCTION

Calibration involves comparison of two standards to establish their relationship by attributing measurement results, correction, and measurement uncertainty [1]. For mass standards, calibration is carried out by directly loading the reference and test mass standards to a mass comparator following a certain order called weighing cycle: ABBA, ABA, $AB_1...B_NA$, where A represents the reference while B is the test mass standard [2]. Among the three weighing cycles, the ABBA is commonly used since it offers least number of repetitive sets, allowing personnel to save more time and effort [2].

The calibration of mass standard is a straightforward process. However, complexity may arise when it comes to calibrating large and heavy masses, i.e. 5 kg or more, using a manual mass comparator where loading and unloading to and from the weighing pan is done repetitively by hand. Doing this routine heavy lifting entirely depending on human strength alone can be disadvantageous making it more prone to human-induced errors such off-centered positioning which can affect the consistency of the calibration result [3]. It also poses risk to the standards and comparators which may when performed carelessly. Moreover, routine lifting can put the calibration personnels' health at risk as it is highly possible for them to develop musculoskeletal disorder (MSD)[4].

The Mass Standards Section of the National Metrology Laboratory of the Philippines (NMLPhil) has twelve (12) mass comparators, only two of these are automatic. Personnel have to resort to manual labor to calibrate the bulk of heavy mass standards. The creation of machine accessories to convey the mass standards to and from the mass comparators is commonly found in several Mass Metrology Laboratories: some of these are in the form of robotic arms [5], linear-moving plate [6], and conveyor type [7].

In this study, a machine prototype consisting mainly of a rotary plate is developed to be used as an accessory of an existing manual mass comparator at the NMLPhil. The prototype will be used to calibrate mass standards ranging from 5 kg to 20 kg with OIML accuracy class of F2.

II. METHODOLOGY

A. Prototype Design

Fig. 1: Main Components of the prototype of the automated rotary plate
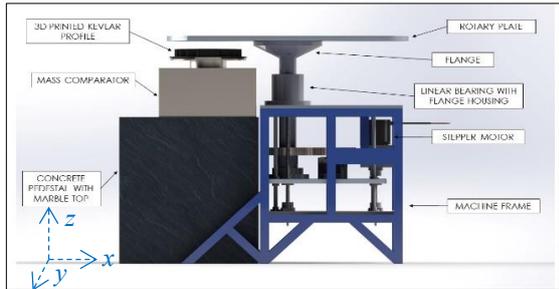
The aluminum plate was designed to have two motions: linear along z axis and rotary along x-y plane. The rotary motion will convey the sample to and from the mass comparator and the vertical motion will allow transfer of the mass standard from the rotary plate to the comparator's weighing pan.

The transfer of the mass standard from the rotary plate to the weighing pan is enabled by fabricating two partner profiles, i.e. the aluminum plate with through holes and the ABS plate with ridges that fit in that aluminum plate through holes. The height of this ridges is enough that, when overlap, it takes over the mass standard from the aluminum plate.

For the main body of the machine, it has three main components. The first set supports the masses loaded in the system, consists of the aluminum plate supported by the main and four support shafts. The second set allows the aluminum plate's linear mechanism. It is powered by a stepper motor and the transfer of motion is through chains and sprockets attached to the lead screws. Support shafts and linear bearings also serve as additional guides in the linear action. The third set enables the machine to perform rotary motion. A stepper motor drives the main shaft through the torque transfer in the gear assembly.

An aluminum machine frame was fabricated to house the assembly and a concrete pedestal was also constructed to level the mass comparators with the machine. The machine frame supports the portability of the design, allowing the user to relocate the machine without disassembling it.

B. Software Development

The automation of the machine mechanisms was made possible by controlling the two stepper motors using an Arduino micro-controller through motor drivers.

After the user manually loaded the mass standards onto opposite ends of the rotary plate, the program then initiates ABBA weighing cycle: the standards were weighed by lowering the aluminum rotary plate to overlap with its partner ABS plate, the standards were switched position by rotating the aluminum plate up to 180 degrees.

The rotary motion was controlled by setting the number and direction of the microsteps of the stepper motor. Whereas, the vertical displacement of the rotary plate is controlled by a proximity sensor, programmed to stop the motion when the plate is lowered down to a specific height. This allows the machine to be more flexible with the manual mass comparators to be used.

C. Evaluation of Results

A repeatability test was performed using the new developed system for 5 kg, 10 kg, and 20 kg mass standards. This was conducted by performing the $A_1B_1B_2A_1$ weighing cycle ten (10) times. The difference of the average Δm_{ci} is calculated each cycle.

$$\Delta m_{ci} = \frac{(B_1 + B_2) - (A_1 + A_1)}{2} \quad (1)$$

Their standard deviation were calculated to evaluate the consistency or repeatability of the data.

The calculated standard deviation is compared to the following two controls:

i. Manufacturer's Declaration s_d – the standard deviation declared in the technical manual of the balance declared by the manufacturer. This reflects the intended accuracy level for which it is designed.

ii. Manual Calibration s_m – the standard deviation calculated from the data obtained from manual performance of repeatability tests

III. RESULTS AND DISCUSSION

A stress and deflection analyses simulation on the aluminum plate and its shafts was performed using SolidWorks to check whether it can withstand the amount of intended load which it will be subjected. An actual flexure test was also performed on the aluminum plate to ensure that it can support the mass standards without deformation.

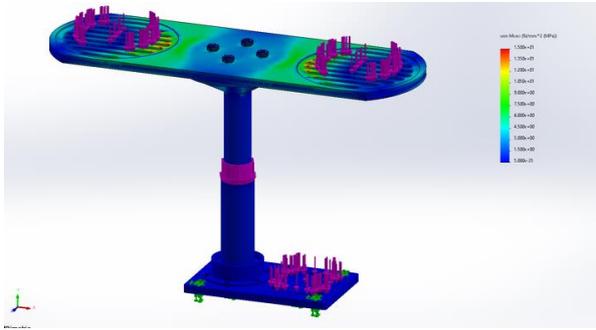Fig. 2: Visual representation of von Mises Stress Analysis

Fig. 3: Actual Assembly of the machine accessory with the mass standard and comparator

The repeatability tests performed with the mass standards 5 kg, 10 kg, and 20 kg using the developed system yielded the standard deviations s_n in the table 1, as compared to the two control standard deviations.

Table 1: Comparison of the standard deviations between the controls and the developed systems

Nominal Value	s_n	s_m	s_d
5 kg	0.0023	0.0021	0.013
10 kg	0.0052	0.0066	0.013
20 kg	0.0086	0.0106	0.013

The percent error was calculated to assess the change in the repeatability of the data with the introduction of the new system.

Table 2: Percent error of the project's standard deviation with respect to the two control standard deviations

Nominal Value	s_n vs s_m	s_n vs s_d
5 kg	-9.52%	74.62%
10 kg	21.21%	60.00%
20 kg	18.87%	33.85%

The percent errors in the Table 2 demonstrates whether the developed system induces improvement in the calibration results with respect to the two controls. Where, positive percentage indicates better repeatability for the system, while negative indicates otherwise. The negative percent error in 5 kg could be attributed to its handleability in terms of its weight and size. Hence, making it easy to manually calibrate for the personnel. The rest of the comparisons show that the developed system improves the repeatability of the balance which can be an effect of the enhanced precision in the positioning of the mass standard due to the calculated and constant movement of the rotary plate.

While the developed system takes approximately five (5) minutes longer per calibration cycle than the manual process with five (5) minutes difference, it is notably faster than the existing automatic mass comparator in the laboratory – allowing the user to save around 35 minutes per calibration cycle.

IV. CONCLUSION

The design of the new system demonstrated durability and stability that satisfies the requirement of its intended application. Through multiple repeatability tests conducted, it is confirmed that the machine consistently performed the prescribed weighing cycle for the mass standards with minimal intervention from the personnel. The system's design and automation also offer high-portability and flexibility which are especially beneficial for personnel conducting onsite calibration of mass standards.

The system produces a significant improvement in terms of the repeatability of the calibration results by ensuring the stable and steady conveyance, loading, and unloading of the mass standard onto the mass comparator.

Overall, the system effectively enhances the consistency of the calibration results while protecting the integrity of the mass standards, the weighing instrument, and the safety of the calibration personnel.

V. RECOMMENDATION

Results and observations showed that the new calibration system works effectively in bettering the repeatability performance of the mass comparator. However, it is recommended to develop an automated

lifter system and be integrated in this new system to fully eradicate the manual lifting of the calibration personnel. Also, further study needs to be conducted to show the accuracy of the results through the conventional mass results due to the conducted calibration. Lastly, application of the new system for heavier weights, greater than 20 kg, should also be explored.

VI. REFERENCES

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