THE NIST MAGNETIC SUSPENSION MASS COMPARATOR: A LOOK AT AUTOMATION

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Abstract: The magnetic suspension mass comparator at NIST is a fully automated mass comparator with the unique feature that it is able to directly compare a mass in vacuum to one in air. The technique is realized by coupling a weighing pan located in air to a mass comparator in vacuum using magnetic suspension. The fully automated system is able to compare up to four masses in vacuum to four masses in air.

1. INTRODUCTION

In support of the coming redefinition of the kilogram, the National Institute of Standards and Technology (NIST) has developed a system for the direct comparison of a mass in vacuum to one in air. While the current definition of the kilogram is realized in air, experiments like the Watt Balance [1] and X-Ray crystal diffraction [2] experiment will realize the new definition in vacuum. However, the dissemination of the new kilogram will still occur in air and a reliable method for transferring from vacuum to air is needed.

The standard method for vacuum to air mass comparison involves measuring surface adsorption using sorption artifacts and applying a correction when the artifact is moved from vacuum to air [3]. This method is indirect and dependent on both surface quality and environmentals. The NIST magnetic suspension mass comparator (MSMC) [4] provides an alternative approach that is direct and not dependent on the surface quality of the mass artifact.

The MSMC is a mass comparator which uses magnetic suspension to directly compare the mass of an artifact in a vacuum chamber to the mass of an artifact located in a separate chamber held at atmospheric pressure. The MSMC, see left inset of Fig. 1, includes the mass comparator, an upper magnetic assembly (UMA), and a lower magnetic assembly (LMA) with attached weighing pan. When the LMA, with attached weighing pan, is magnetically suspended it becomes part of the mass comparator and its mass value can be removed from subsequent measurement calculations. Therefore, a mass placed on the mass comparator in vacuum can be measured with the LMA and weighing pan magnetically suspended and its value can be directly compared to a mass placed on the magnetically suspended weighing pan and LMA. This allows for a direct mass measurement between vacuum and air. A key to ensuring reliability for these precision measurements is automation. Here, we outline the automated mass handling system that we have incorporated into the MSMC.

2. MAGNETIC SUSPENSION

Looked upon as a black box, the MSMC is no different than any other mass comparator. In fact, the mass comparator located in the upper vacuum chamber is a commercial comparator with a resolution of 10 µg. The uniqueness of the system lies in the magnetic suspension and mass handler that was designed around it in the lower chamber. The magnetic suspension, described by Stambaugh [5], works in the following way. A Hall sensor is placed between the UMA and the LMA to detect the motion of the LMA. A fixed separation distance, and thus magnetic field exists, where the magnetic force upwards on the LMA is almost balanced by the downward force of gravity. However, because such a system is not stable, a feedback loop is used to drive an electromagnet coil to provide a compensating force to stabilize the suspension.

3. AUTOMATED MASS HANDLING

The mass handling in the upper chamber is carried out using the commercial controller that comes with the mass comparator. Software was written to interface with the mass comparator and incorporate it into the entire mass comparison procedure for the MSMC. To accommodate the uniqueness of the magnetic suspension, a custom mass handler was designed. The two main parts consist of the mass exchange system and the automatic suspension system.

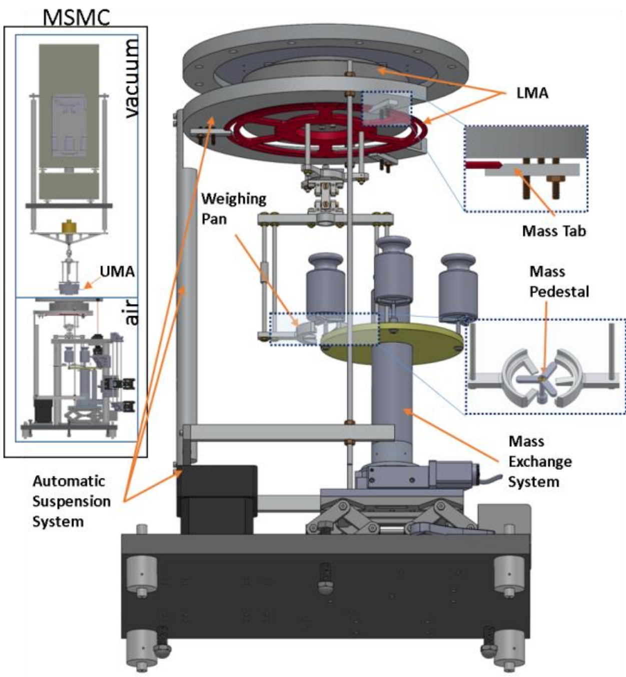

Figure 1: Illustration of MSMC.

The mass exchange system consists of a motorized rotating stage and vertical stage. The rotating stage is stacked on top of the vertical stage. An aluminum cylinder is mounted on the rotating stage and the turntable with mass pedestals is placed on top of that. The cylinder provides a large separation between the magnet and motor; minimizing a possible source of systematic error. The weighing pan that hangs from the LMA consists of two arms rigidly held in place by four bars, see zoomed inset in Fig. 1. By separating the holder of the weighing pan, the mass pedestal can rotate directly through the weighing pan during mass changes.

During a measurement of a mass in the lower chamber, the following procedure is followed. The turntable is rotated so the mass sits directly above the weighing pan. The mass is lowered until contact is made with the weighing pan. The mass is then lifted on and off a set number of times to ensure it is centered. The stage is then lowered and rotated 45 degrees, leaving the mass on the weighing pan. When the mass to be measured is in the upper chamber, the stage is lowered at the 45 degree offset, leaving no mass on the weighing pan. The next step of a measurement involves the automatic suspension.

The automatic suspension works by utilizing a motorized vertical stage to lift the LMA and weighing pan (plus mass) to the ideal suspension height. A predetermined setpoint value for the magnetic field is used to determine at what position magnetic suspension should take place. The vertical stage lifts the LMA up and a control progam [5] monitors the field. When the field reaches the setpoint, the magnetic suspension code lifts the LMA off the mass tabs. The stage is then lowered slightly to ensure it is completely out of contact with the suspended LMA. At this step, magnetic suspension is realized and stability is reached in less than 30 seconds. The automated lifting greatly reduces the time it takes for the magnetically suspended object to stabilize compared to manual placement.

Upon finished the weighing, the setpoint is lowered, effectively lowering the suspended assembly. The vertical stage is raised, bringing the mass tabs into contact with the LMA and the suspension is turned off. The stage is lowered and the mass exchange procedure is reversed. When finished, the system is back to its starting state, ready to measure again.

4. CONCLUSIONS

The MSMC provides a new and unique way to disseminate mass from vacuum to air. The measurement procedure described above is completely automated, allowing for a series of measurements to be performed without user intervention. Preliminary tests have shown good agreement for basic mass comparisons. Currently the full precision of the measurement is constrained by the comparators’ resolution (1 mg), in the coming weeks the balance will be exchanged for the 10 µg comparator and full precision will be realized.

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