The Impact of the New SI on Industry

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Abstract

There is a draft resolution from the General Conference of Weights and Measures (CGPM) inviting the International Committee of Weights and Measures (CIPM) to propose a revision of the International System of Units (SI). While the actual implementation of any such change is still years away, it is important to plan how the communication of the changes and implementation of the revision would actually occur. The proposed revision to the SI has been widely discussed at National Measurement Institutes (NMI's) and to a lesser extent, industry. Although the magnitude of the changes in the proposal are generally too small to be seen by most industrial organizations, it is important to communicate why the change is being made, how it will occur, and what organizations must do in order to maintain traceability to the SI.

This paper provides background information regarding the possible changes to the SI, and Fluke's role in realizing the changes. It identifies industrial measurements that may be significantly affected by a redefinition, and addresses the roles and responsibilities that organizations such as the NCSLI and companies like Fluke have to effectively communicate the revision of the SI to industry measurement professionals.

Learning Objectives

After reading this paper, the reader should be able to understand:

- That the SI will be redefined at some point in time
- An approximate timeframe for redefinition
- An initial understanding of whether the redefinition will potentially affect their organization or not
- The role major industrial organizations will play in educational activities associated with a redefinition of the SI
- How measurements associated with the redefinition of the SI will be disseminated to industry

Introduction

In October of 2011, the CGPM may be meeting to consider a proposal to address the last of the seven base SI units that are still defined in terms of a material artifact[1]. The proposal would change the definition of the kilogram, which has remained unchanged since the first meeting of the CGPM in 1889, to a value based upon a constant of nature. The kilogram would be the most significant of the proposed changes to the SI, as it has been in place the longest amount of time. Other quantities such as the ampere, mole and candela are all defined in terms of the kilogram, and would also be affected by any redefinition of the kilogram. The draft of the proposal would revise the SI as follows:

- The ground state hyperfine splitting frequency of the caesium 133 atom $\Delta\upsilon(^{133}Cs)_{hfs}$ is exactly 9 192 631 770 hertz
- The speed of light in vacuum c is exactly 299 792 458 metre per second
- The Planck constant *h* is exactly 6.626 06**X** $\times10^{-34}$ joule second
- The elementary charge *e* is exactly 1.602 17**X** $\times10^{-19}$ coulomb
- The Boltzmann constant *k* is exactly 1.380 6**X** $\times10^{-23}$ joule per kelvin
- The Avogadro constant N_A is exactly 6.022 14**X** $\times10^{23}$ reciprocal mole
- The luminous efficacy K_{cd} of monochromatic radiation of frequency 540 $\times10^{12}$ Hz is exactly 683 Lumen per watt

The underlined and bold values of x in the definitions are to be added based on the most recent CODATA[2] adjustment as described in the referenced paper.

The SI will continue to have the present seven base units, but now instead of the kilogram being defined by the artifact kilogram, it will be defined in terms of the Planck constant. The ampere will continue to be the unit of electric current, but it will be defined by the elementary charge. The kelvin will be the unit of thermodynamic temperature, but it will be based upon the Boltzmann constant. Lastly, the mole will be defined in terms of the Avogadro constant.

From the perspective of industry, the following questions naturally arise:

1. When is this going to happen?
2. How much will it affect the reference values of my standards, their associated uncertainty, and any measurement processes?
3. Who is going to help explain what these changes are, and why they are occurring, to my company and to my customers?
4. How will the change in the SI get disseminated to my organization?

When is this going to happen?

Fortunately for us, the short answer for this is, not very soon. The first thing that would have to occur for a redefinition to be realized is that the conditions that were set out in the 23rd meeting of the CGPM in 2007[3] would have to be met. The independent experiments for Planck's constant have not reached a level of sufficient agreement to be able redefine the constant and maintain a small enough uncertainty in the watt balance results. Also, an experiment to redefine the Boltzmann constant has been completed with excellent results, but there has not been a second experiment that can confirm the results of the first experiment with sufficiently small uncertainty. For this reason, the CIPM is not ready to make a final proposal for the revision of the SI[4]. The CGPM meets once every four years, so the next time that this matter would be scheduled to be discussed is in 2015. If we account for sufficient time to produce documents to realize and implement the change, we are probably not going to see anything before 2016 at the earliest.

How much will it affect the reference values of my standards, their associated uncertainty and any measurement process?

In order to realize the definitions of the proposed new base units, it will be necessary to develop specific "*mises en pratique"*, which are a set of instructions on how the definitions are realized in a practical way at the highest level, which will allow for subsequent dissemination of the measurement unit. An example of a "*mise en pratique"* is that the ampere can be realized by using Ohm's law, the unit relation A=V/Ω, and using practical realizations of the SI derived units of volt V and ohm Ω, based on the Josephson and quantum Hall effects, respectively.[5]

Because of the redefinition of Planck's constant and the elementary charge, and that the Josephson constant is based on the ratio *2e/h*, the Josephson constant will also change. The effect of the SI change on the practical realization of the volt is approximately 19×10^{-9}, which will only be seen by industrial laboratories that use Josephson Voltage Systems during the most precise interlaboratory comparisons. The author only knows of one organization in the United States that accepts industrial customers that would have to consider the implications of this redefinition.

As discussed previously with the Josephson constant, the von Klitzing constant is based on h/e^2, and would be adjusted as well. The effect on resistance measurements that were realized through the quantum Hall effect would be approximately 22×10^{-9}, which could possibly need to be addressed by organizations that send their highest quality resistors to a National Metrology Institute for measurement.

The effect on mass measurements[6] is not known at this time, but would be anticipated to be within a few parts in 10^8. This quantity will only be seen at the best NMI to industry interactions.

The mole, now based on the Avogadro constant instead of its previous definition being tied to the kilogram is not anticipated to change by more than a few parts in 10^9.

The Candela is defined in terms of W/sr (Watts per steradian, the SI unit of solid angle). As the watt is also defined as $s^3m^{-3}kg^{-1}$, any uncertainty associated with the redefinition of the kilogram will also flow through to the Candela.

Perhaps the most challenging quantity in the redefinition will be the kelvin. Presently, the kelvin is defined in terms of the triple point of water of defined isotopic composition. If the kelvin is defined in terms of the Boltzmann constant, then the triple point of water becomes a quantity to be determined experimentally. The value chosen for the Boltzmann constant has a relative uncertainty of approximately 1 x 10^{-6}. This equates to an approximate uncertainty of 0.25 mK. This could potentially result either in a redefinition of the triple point of water, or in an expansion of uncertainty. Presently, NMI's and even a select few industrial laboratories produce triple point of water cells with an uncertainty less than 0.1 mK. There is no present solution to this issue, but perhaps the 0.25 mK uncertainty could be added as a fully covariant term that could drop out for comparison measurements. This is certainly a matter that must be addressed during a redefinition.

Who is going to help explain what these changes are, and why they are occurring, to my company and to my customers?

Before any measurement values can be disseminated to industry, information and knowledge must first be communicated. In order to maximize the successful transition to a new SI definition, the CIPM and NMI's must partner with industry to develop publications with appropriate levels of complexity for various audiences within industry. The strongest potential partners for this are the companies that supported experiments associated with the redefinition, such as Fluke Calibration, and professional organizations such as NCSL International.

Fluke Calibration played a critical role in the latest Boltzmann experiment performed by PTB, the National Metrology Institute of Germany. In PTB's experiment, the Boltzmann constant was determined by dielectric constant gas thermometry[7]. In order to achieve the desired level of uncertainty for the experiment, helium had to be measured in both gauge and absolute pressure up to 7 MPa with uncertainties less than 1 x 10^{-6}. At the time of the experiment design, the world's most accurate determination of pressure in this range was 5 to 7 x 10^{-6}. PTB worked with Fluke Calibration to develop a pressure balance (deadweight piston gauge) that achieved less than 1 x 10^{-6} uncertainty. The resulting product is now sold as the Fluke Calibration PG9607 shown in Figure 1.

Figure 1, the Fluke Calibration PG9607

While we cannot predict exactly how organizations like Fluke will respond in the future, as it usually is with metrology, a review of historical performance can be a good indicator of how we will respond. In 1990, the volt and ohm were redefined based on the Josephson and quantum Hall effect[8]. The resulting shift of 9.264 x 10^{-6} for the volt and 1.69 x 10^{-6} for the ohm in the United States was very significant to Fluke. Fluke was manufacturing the 5700A at that time, and the effect of the 1990 volt change was approximately 100% of the one year specification for DC voltage. This meant that not only was the change significant to the top tier users of NMI measurement services, but it was also very significant to any calibration laboratory that owned a Fluke 5700A. In order to communicate the change to the 1990 volt and ohm, Fluke produced an application note shown in Figure 2, "Changing to the 1990 Volt and Ohm." While the proposed upcoming changes in the SI are not nearly of the same magnitude as the volt and ohm change in 1990, most likely Fluke will write a new application note that would encompass all of the changes to the SI and how it would affect customers of all Fluke products.

FLUKE AND PHILIPS – THE GLOBAL ALLIANCE IN TEST & MEASUREMENT

Application Note

Changing to the 1990 Volt and Ohm

Introduction

On January 1st, 1990, the U.S. National Institute of Standards and Technology (NIST), and other national standards organizations worldwide, will establish new values for the volt and ohm. These values are based on the Josephson effect for the volt and the Quantum Hall effect for the ohm and are consistent with the International System of Units (abbreviated SI) established throughout the industrial world. This change will benefit trading nations by establishing a common standard and international consistency of electrical measurements.

National labs have made similar adjustments in the past. For example, the last adjustment of the U.S. volt occurred in 1969 and was of about the same magnitude as the upcoming change. At that time, only a very small percentage of the instrument population was affected and those instruments were generally found in standards laboratories. Today however, a much larger proportion of the instrument base is impacted by these changes. Such high-accuracy instruments are now found not just in the standards lab, but also in the calibration lab, the manufacturing environment, rental services, equipment pools, service and repair facilities, etc.

This Application Note briefly describes the changes that are being made, what the changes mean, and how to implement them.

The Changes Being Made

The amount of change required to bring the volt and ohm in line with the new representations will vary from country to country. For the U.S., the adjustment to be made for the volt is +9.264 parts per million (ppm) and for the ohm is +1.69 ppm, as indicated in Figure 1 and Table 3. Since the units of both the volt and the ohm will increase for most countries, the value assigned to fixed standards will decrease. To avoid confusion as to the size and sign of the correction, it is best to make the change (of fixed standards) by multiplying the current value (the "old" value) by a correction factor.

For example, in the U.S., a Fluke Model 732A Reference Standard which produces 10.0000234 "old" volts will produce 9.9999308 SI volts ("1990" volts). The 9.9999308 SI volts is derived by multiplying 10.0000234 times 0.99999074 (the correction factor for the U.S. volt). A Fluke Model 742A-10K Resistance Standard which has a current value of 9.9999892 kΩ will have a value of 9.9999723 SI kΩ ("1990" ohms), and is obtained by multiplying 9.9999892 by 0.99999831.

Values for fixed standards in other countries may be adjusted similarly using the information in Figure 1 and Tables 3 and 4. Using France (LCIE) as an example, the voltage correction is 0.99999326 (1-6.74X10E-6) and the resistance correction is 0.99999943 (1-0.66X10E-6).

Also, the value for current will change as a function of the changes to the volt and ohm. In France, the change in the Unit of Current will be +6.08 ppm. The correction multiplier for current will be 0.99999392 (i.e, 0.999990326/0.99999934).

The watt also changes. In France the correction multiplier for power is 0.99998718 [$(0.99999326)^2/$ 0.99999934] since $P=V^2/R$.

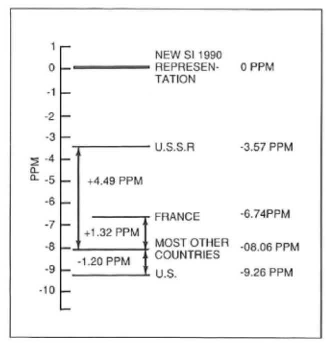

Figure 1. A graphical comparison of the value of the present representation of the volt of various countries.

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Figure 2, Fluke Application Note

Another opportunity to disseminate information could be through social media. Fluke presently maintains a Facebook page. In January the Fluke Facebook page received a post regarding the possible change in mass of the International Prototype kilogram. This is good evidence that there is interest in this subject by our followers. When the SI is redefined, it would be important to have communications developed that explain the changes in a manner that could be relatively easily understood. For now, it is important to communicate that we are aware of the issue and that we will be ready to share the information when the redefinitions occur.

Figure 3, Example of Communication Through Social Media

While some of the major industrial companies may be communicating an SI redefinition in the manner previously described, it will also be important to utilize professional organizations, such as NCSL International to support communication and educational activities associated with an SI redefinition.

In 1989, NCSL formed Technical Advisory Group 91.4.1 to communicate the change of the 1990 volt and ohm. The members of the group included test equipment manufacturers, staff from national laboratories, chemical and utility companies. The mission of the committee was to educate the metrology community on the changes to the volt and ohm. The committee developed a document on practical guidance for implementation of the changes, and spoke at local NCSL meetings to provide a forum for questions and answers.

How will the change in the SI get disseminated to my organization?

The dissemination of measurements from a redefined SI would need to be a planned activity. Hopefully organizations would know if they were affected by the SI redefinition through the educational efforts described in the previous section. The activities of dissemination should be classified by the following two functions:

- Organizations that perform calibration services on devices whose reference value and uncertainty would be affected by redefinition (Traceability Provider)

- Organizations that own and utilize devices whose reference value and uncertainty would be affected by redefinition (Traceability User)

Organizations identified as Traceability Users would have to coordinate closely with Traceability Providers. If there was an effective date of the redefinition, for example, January 1, 2015, it may be possible for Traceability Users to submit their reference standards for calibration shortly before the effective date, with a request to perform a calibration to the redefinition. It would be important for the Traceability Provider to provide a report of calibration the clearly indicates that the calibration was performed to the redefinition. For the change to the U.S. volt and ohm in 1990, a "SI 1990" logo was developed by the NCSL that was used on calibration reports and on a sticker that was affixed to devices calibrated to the new definition. While it may not be practical to use a sticker for most reference standards affected by the upcoming redefinition, the development of a new logo for use on calibration reports may be an effective way to communicate the change.

Figure 4, SI 1990 Logo Developed by NCSL

Conclusion

At this point, it would seem that any redefinition of the SI would not be imminent. As we progress towards a redefinition of the SI in the next few years, it will be important to carefully consider the repercussions of new definitions on measurement uncertainty and "*mises en practique*". Plans must be developed and executed in order to educate and disseminate knowledge to the industry before any transfer of traceable measurements associated with a new SI definition can occur.

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