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The formation of metrology as government regulated activity in France

Abstract. *The article has discussed the historical process of development of metrological activity in France. It was revealed that the history of metrology is considered as an auxiliary historical and ethnographic discipline from a social and philosophical point of view as the evolution of scientific approaches to the definition of individual units of physical quantities and branches of metrology. However, in the scientific literature, the little attention is paid to the process of a development of a centralized institutional metrology system that is the organizational basis for ensuring the uniformity of measurements. It was shown that traditionally there are two periods of development of metrology based on the unification of weights and measures: the association under Charlemagne and the introduction of the decimal metric system during the French Revolution. Because this division has a mixed scientific and organizational basis, a new periodization of the development of French metrology from the position of state regulation was proposed. The highlighted stages include the primitive period and the first city-states, the time of the domination of the Roman Empire, the era of the coexistence of many measures, the chapters of Charlemagne, the feudal practices of the Middle Ages, the creation of royal standards under Henry II, the introduction and dissemination of the decimal metric system, the emergence of metrological institutes, laboratories, centers. At the State level the first step in organizing a centralized institutional metrology system was the creation of a testing laboratory, the second was the creation of National Metrological Bureau, national bodies for metrology, and the third was reorganization of the system and appointment of the National Testing Laboratory as the governing metrological body of France.*

Thus, the French metrology system has experienced many crises and upheavals in the process of its formation. However, France today is one of the most experienced and respected countries in the field of metrology, and at the international level, it was the one who laid the foundations for new metrological agreements, as well as the social, philosophical, scientific, political and geographical area of the new system of measures and weights.

Keywords: *unification of weights and measures; metric system; metrological chaos; system of units of physical quantities; metrological activity*

Introduction.

It is common knowledge that today metrology is a fundamental element of the development of science, industry, and society. Although the importance of metrology in economics of resource reallocation cannot be overemphasized, the term "metrology", that denotes the science of measurements, was introduced only in 1780, and earlier the metrological activity was considered a social practice (Cotteret, 2003, p. 82). This and other aspects are encouraging to study of the historical context of metrology, that allows to trace the occurrence, the spread, the change and disappearance of measures systems, its individual units, and the practice of their use. This, in turn, makes it possible to draw conclusions about the level of socio-economic development of society, international trade intensity, foreign policy relations, and at a less global level – to identify development trends both in the field of metrology and science generally. According to J. Kovalevskiy, head of the French National Metrology Bureau from 1994 to 2005, this task becomes more urgent due to the globalization of the modern world "the metrology is subject to the development of an unprecedented amplitude" (Kovalevsky, 2005, p. 3). There are enough known events in the history of metrology that have global significance for science, and especially it is more interesting to try to understand the difficulties faced by society and what kind of answers were found then to overcome them. From this perspective, the French experience may be cognitive, since France was the first to reform the measures system toward its unification and was among the first countries of the initiators of the signing of the Metric Convention.

J.-C. Hocquet and his fundamental work "Historical metrology" (Hocquet, 1995; Hocquet, Garnier & Woronoff, 1989) and other works made a significant contribution to the study of the history of French metrology about the origin and spread of the metric system, the variety of measures and weights of ancient France, measurements and weighing over the centuries, etc. Moreover, French scientists explore the history of measures of length and area (Reguin, 2021), water measurements (Mathieu, 2001), teaching metrology (Cotteret, 2003), metrology practices before the French Revolution (Guyotjeannin, 1987), the relationship between metrology and standardization (Bryden, 2012), the overall history of measurements (Jedrzejewski, 2020), the impact of individual organizations on French metrology (Petitgirard, 2015). Studying of the works shows their overall perception of metrology as a universal human collective

activity, which, however, is not practiced uniformly. Moreover, these differences can be simultaneously both the consequence and the reason for the need for change existing principles, trends and mechanisms in science, legal systems, practices that reside within metrology. However, the scientific literature paid very little attention to the process of creating a centralized institutional metrology system that is the organizational basis for ensuring the uniformity of measurements.

In this regard, the purpose of article is to study the process of the formation of metrology as an activity, regulated by government in France as one of the countries with global influence in this area.

Theoretical foundations.

Based on the sources mentioned above it can be argued that in the scientific literature, there are several approaches to the study of the history of metrology: it is treated as an auxiliary historical and ethnographic discipline; it is treated from a social and philosophical point of view; it is treated as an evolution of scientific approaches to the definition of individual units of physical quantities and branches of metrology. In the aspect of the state organization of metrological activities in France decided to allocate two periods: the association under Charlemagne and the introduction of the decimal metric system during the French Revolution. These aspects are based on the unification of weights and measures. In our opinion, such a division is not correct enough, since it has a mixed scientific and organizational basis, mainly associated with the definition of units of physical quantities. And, although the achievements of scientific metrology are of key importance for the development of this activity, we propose to divide the history of French metrology from the position of state regulation into ten stages, a description of which is presented in the section «Results and discussion»: 1) the incipience of weights and measures; 2) the first form of legal metrology; 3) “metrological chaos”; 4) chapters of Charlemagne; 5) feudal practices; 6) the creation of royal standards; 7) the introduction of the decimal metric system; 8) the plurality of metrological organizations; 9) national metrological organizations; 10) creation of a unified state sustainable structure.

Results and discussion.

At the first stage of the existence of human civilization, in the Paleolithic era, hunters and gatherers, apparently, did not have metrological practice. However, the work (Jedrzejewski, 2020) said, that at that time there were objects that looked like graduated rulers, namely fragments of bones or stones with evenly spaced parallel incisions, while there is no one confirmations of their use as measuring instruments. Climate softening, the transition to a sedentary lifestyle, the rapid evolution of human societies led to the Neolithic revolution, namely, to the transition from gathering and hunting to agriculture and animal husbandry, on the territory of modern France this happened about 10,000 BC. In addition, the emergence of the need to exchange surplus

agricultural products inevitably led to the invention of the first stone measures of weight.

The gradual development of society led to the emergence of city-states and large trading colonies such as Massilia (by around 600 BC, modern Marseille), in which the processes of economic exchange were significantly different from average Neolithic villagers. New forms of economics have transformed social activities related to the production, management, establishment, and leadership. Redistribution of production, tax increases, exchange of surplus in the markets, trade with neighboring cities led to the need for accounting and metrology. The fact that the oldest weights are unmarked indicates to a time where "metrological activity was not subordinate to authorities, but existed on trusting relationships between people and groups" (Cotteret, 2003, p. 104).

In antiquity on the territory of modern France (2nd century BC – 5th century CE) all types of taxes and fees in monetary or raw material form were calculated by Roman measures. Their standards were often made of stone and kept in the Temple of Jupiter in Rome, but also in the most visited shopping places. There was a position of an inspector for checking weights and measures, who had the right to destroy false measures (Hocquet, 1995). This fact as well as control of the production of coins under the leadership of the proconsul of Gaul in Lyon could call it the first form of legal metrology in France.

After the fall of the Western Roman Empire, the tribes of the Burgundians, Visigoths, and Franks came to Gaul, which, in turn, brought their measuring systems. The coexistence in the same time and space of these, as well as Roman, Arabic, Greek, Gali measures and weights has led to what many researchers call "metrological chaos". The first attempt to regulate it at a national level was performed by Charlemagne in 779. He combined measures, weights, and coins and they still acquired a fixed value throughout the empire even if they retained the Roman name. In addition, he increased the numerical values of the measures, which changed the entire system, and reorganized the monetary system, basing it on a new standard of weight, namely, the grain of wheat. Such acts showing that Charlemagne "had an understanding of the essence of the measure and its structuring role" (Cotteret, 2003, p. 119). During his reign, (768-814) standards were stored in churches and his palace, and inspectors, whose activities were intended to guarantee fair trade, regularly checked all measures. It took Charlemagne almost 20 years to introduce a unified metrological system that operated only under his rule. He was thinking big for his time, and his empire was too large and did not have a sufficiently developed transport infrastructure to support uniform measures throughout its territory (Hocquet, Garnier & Woronoff, 1989).

During the Middle Ages, the unified system of measures and weights of Charlemagne underwent more and more changes, namely, feudal Lords declared their sovereign rights to measurements, established measures, determined their numerical value depending on the circumstances. The standards were in the custody of feudal judges, the vassals focused their measures on the measures of the Lord. There was a paid official position, which requires swearing to the Lord and consisted in tracking

fraud and punishing violations (Hocquet, 1995). Without official regulation, collections and rule books appeared that systematized local metrological practices and gradually replaced Charlemagne's obsolete chapters.

In 1321, Philip V attempted to unify measures, weights, and coins. He ordered the assembly of the Estates General to resolve this issue and work on reform, but he met the categorical refusal of the Lords and clergy, motivated by the fact that this unification supported only royal interests. Being the forming of state representative institutions, which had convened at the initiative of the royal government to assist the government. The Estates General nevertheless sought to find ways to contain it and advance the interests of the estates. At their insistence in 1558, Henry II proclaimed a decree on the unification of measures in all territories falling under the jurisdiction of the court of the Paris parliament, and "all feudal measures had to correspond to the royal standard, placed in the Paris city hall under the supervision of the mayor or his deputy" (Cotteret, 2003, p. 128).

Considering the flourishing royal absolutism, Estates General meetings had no longer held until 1789 despite the accumulated contradictions in society that demanded cardinal reforms, including and in the field of metrology activities. Previous attempts by the Minister of Finance A. Turgot to establish the unity of measures because of a unit of length throughout the entire territory of the state did not find support from the last French king Louis XVI. Also, the next Minister of Finance J. Necker expressed doubts about the success of this idea, given the changes that would need to be made in all areas of activity (Cotteret, 2003, p. 131). Therefore, among other requirements also were the numerous books of complaints of the provincial assemblies, sent with deputies to the Estates General, contained various metrological problems of that time. These books gave rise to many abuses and fraud at the local level, and massively demanded the unification of weights and measures, as well as their calibration and labeling.

By the beginning of the Great French bourgeois revolution, the commission of the Academy of Sciences on the project of uniformity of weights and measures concluded that the scientific basis for this was sufficiently developed. In 1790, the report "Observations of the Royal Agricultural Society on the Uniformity of Weights and Measures" was submitted to the National Assembly. This report summarized the current scientific research in the field of metrology at that time. The result was a decree of the National Assembly on the rationing of measures and weights, prescribing to draw up a scientific substantiation of a new system of measures and a table of the ratio of new and old measures, to take an inventory of local measures, and to make temporary standards. Moreover, in 1795, the unification of measures and weights law was adopted, which introduced the decimal metric system in France, standards uniform for the whole country, the procedure of their manufacture, storage, verification, and the position of an auditor of standards in each district (Hocquet, Garnier & Woronoff, 1989). Although in 1812 and 1816 Napoleon Bonaparte issued decrees, leading to change the original purity of the decimal metric system, this law remained basic and was revived

in 1837 when the metric system became mandatory for all commercial transactions in France.

The year before the law in 1795, the National Conservatory of Arts and Crafts (Cnam) was created, designed to produce and distribute metric standards, both within France and in other countries. In 1848, national standards were deposited at Cnam from the Provisional Bureau of Weights and Measures of the Department of Commerce. This organization became one of the leading in the metrology field in France. In addition, this organization became the center of all promotional activities for the decimal metric system in the XIX century and slowly but surely spread in Europe. Back in 1797, French Foreign Minister Charles de Talleyrand organized the first international meeting on metrology to verify the calculations of the numerical value of the meter. However, the World Exhibitions of 1851, 1855, and 1867 show significant differences in measures in different countries. In this regard, the International Metrology Commission was created in 1869, the French section of which took on the task of implementing a new standard for the meter. The result of the commission's activities was the signing in Paris in 1875 of the International Metric Convention and the creation of the International Bureau of Weights and Measures (BIPM).

The next step in the development of the French metrological system was the creation of the "National Scientific and Permanent Bureau of Weights and Measures" in 1880 based on Cnam, which had previously met the needs of "conventional metrology" rather than scientific (Petitgirard, 2015, p. 22). Rapid industrialization at the end of the 19th century and a growing need for measuring instruments and their verification in the industry led to the creation in 1901 testing laboratory (LE) on the initiative of the Society of Civil Engineers. The laboratory was based on Cnam and administered by the Ministry of Foreign Trade and the Chamber of Commerce and Industry. In addition, since 1900, several reputable organizations have been operating in the field of metrology in France at the same time, namely, Central electrical laboratory (LCE, from 1882), Observatory of Paris of time measurement, Commissariat for Atomic and Alternative Energy (CEA, from 1945). The absence of a centralized integrated system, the unclear definition of the mission and objectives of LE, lead to the crisis of the 1930s. Apart from electricity and lighting, France was not represented on the International Committees for Weights and Measures; metrology is divided between LE, LCE, BIPM, and private laboratories, LE fails to maintain a balance between measuring instruments control and scientific activities.

This generally continued until the late 1960s, when rapid economic growth at "The Thirty Glorious" exacerbated existing metrology challenges. He showed the need for a testing and control laboratory to serve the industry and for basic, scientific, referral testing and research (Petitgirard, 2015). This led to the creation in 1969 of the National Institute of Metrology (INM) for scientific research, the National Testing Laboratory (LNE) for the verification and calibration of industrial measuring instruments, the National Bureau of Metrology (BNM) to coordinate the activities of metrology organizations. This step ended several decades of debates, pioneered the 35-

year restructuring of French metrology, and created an inter-agency coordination mechanism for the major players in metrology, facilitating the development of metrology activities, funding and interaction with industry. Until that time, in France, unlike in other countries, there were no single agency to manage metrological activities at the national level.

A natural consequence of this, and also following international trends, in 1982 the National Testing Network (RNE) was organized, whose purpose was to identify and mark the conformity of testing laboratories, and in 1993 the BNM Committee for Accreditation of Calibration Laboratories (FRETAC) was established. In 1994, the accreditation of laboratories and certification bodies transferred to the specially created French Accreditation Committee (COFRAC), and the BNM received the status of a public group (GIP). Created over several years with updates, that were not obvious, the situation at BNM proved to be completely incompatible with its continuing responsibilities in industry, commerce, healthcare, and the environment. For this reason, in 2005, BNM was finally taken over by LNE, a stable structure that in this case became the National Laboratory for Metrology and Testing. Today the LNE manages metrology in France in cooperation with Cnam, CEA, and the Paris Observatory under the leadership of the Ministry of Economics.

Conclusions.

Today the metrology is the universal language of science and technology, but its development throughout history has varied from a form of support for private interests to the exchange of a universal public metrological good. The latter became possible thanks to the state regulation of metrological activity, which organizationally ensures and maintains the uniformity of measurements. Several historical attempts to put it into practice have been identified. However, the first effective step in organizing a centralized institutional metrology system was the creation of the LE, the second was the creation of the BNM, the national metrology body, and the third step was the reorganization of the system and the LNE assignment as the governing metrology body in France. In addition, although we contested the traditional division of the development of metrology in France based on the unification of weights and measures, nevertheless, it should be noted that there is a fundamental difference in the organization of ancient and new measures and weights. It lies not only in the metrological principles that served as the basis for the decimal metric system but also in the equalization of citizens' rights in access to the public good.

Generally, the French metrological system in the process of its formation has experienced many crises and upheavals. However, today France is one of the most experienced and reputable countries in the field of metrology and at the international level, it was the one who laid the foundations for a new metrological agreement and social, philosophical, scientific, political, and geographical area of the new system of measures and weights.

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The authors declare no conflict of interest.

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Становлення метрології як державно регульованої діяльності у Франції

Анотація. *У статті розглянуто історичний процес розвитку метрологічної діяльності у Франції. Виявлено, що історію метрології розглядають як допоміжну історичну та етнографічну дисципліну, з соціальної та філософської точок зору, як еволюцію наукових підходів до визначення*

окремих одиниць фізичних величин і галузей метрології. Однак, в науковій літературі приділено мало уваги процесу створення централізованої інституційної метрологічної системи, яка є організаційною основою забезпечення єдності вимірювань. Встановлено, що традиційно виділяють два періоди розвитку метрології, заснованих на уніфікації мір і ваг: об'єднання за Карла Великого і поява десяткової метричної системи під час Французької революції. Оскільки такий розподіл має змішану науково-організаційну основу, запропоновано нову періодизацію розвитку французької метрології з позиції державного регулювання. Виділені етапи включають первісний період і перші міста-держави, час панування Римської імперії, епоху співіснування безлічі мір, капітули Карла Великого, феодальні практики Середньовіччя, створення королівських еталонів за Генріха II, введення і поширення метричної десяткової системи, виникнення метрологічних інститутів, лабораторій, центрів. На державному рівні першою спробою організувати централізовану інституційну метрологічну систему було створення випробувальної лабораторії, другим – Національного метрологічного бюро, національного органу з метрології, а третім – реорганізація системи і призначення Національної випробувальної лабораторії керівним метрологічним органом Франції. Французька метрологічна система в процесі свого становлення зазнала безліч криз і потрясінь. Проте, Франція сьогодні є однією з найдосвідченіших і авторитетних країн в сфері метрології, а на міжнародному рівні саме вона заклала основи нового метрологічного договору, а також соціальний, філософський, науковий, політичний і географічний ареал нової системи мір і ваг.

Ключові слова: *уніфікація мір і ваг; метрична система; метрологічний хаос; система одиниць фізичних величин; метрологічна діяльність*

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Становление метрологии как государственно регулируемой деятельности во Франции

Аннотация. *В статье рассмотрен исторический процесс развития метрологической деятельности во Франции. Выявлено, что историю метрологии рассматривают как вспомогательную историческую и этнографическую дисциплину, с социальной и философской точек зрения, как эволюцию научных подходов к определению отдельных единиц физических величин и отраслей метрологии. Однако, в научной литературе уделено мало*

внимания процессу создания централизованной институциональной метрологической системы, которая является организационной основой обеспечения единства измерений. Установлено, что традиционно выделяют два периода развития метрологии, основанных на унификации мер и весов: объединение при Карле Великом и появление десятичной метрической системы во время Французской революции. Поскольку такое деление имеет смешанную научно-организационную основу, предложено новую периодизацию развития французской метрологии с позиции государственного регулирования. Выделенные этапы включают первобытный период и первые города-государства, время господства Римской империи, эпоху сосуществования множества мер, капитулы Карла Великого, феодальные практики Средневековья, создание королевских эталонов при Генрихе II, введение и распространение метрической десятичной системы, возникновение метрологических институтов, лабораторий, центров. На государственном уровне первым этапом организовать централизованную институциональную метрологическую систему было создание испытательной лаборатории, вторым – Национального метрологического бюро, национального органа по метрологии, а третьим – реорганизация системы и назначение Национальной испытательной лаборатории руководящим метрологическим органом Франции. Французская метрологическая система в процессе своего становления испытала множество кризисов и потрясений. Тем не менее, Франция сегодня является одной из самых опытных и авторитетных стран в сфере метрологии, а на международном уровне именно она заложила основы нового метрологического договора, а также социальный, философский, научный, политический и географический ареал новой системы мер и весов.

Ключевые слова: *унификация мер и весов; метрическая система; метрологический хаос;, система единиц физических величин; метрологическая деятельность*

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