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DEVELOPMENT OF AN ANALOGICAL AND DIGITAL TAPE AND SCALE CALIBRATOR AND THE COMPARISON BETWEEN CALIBRATION METHODS

José Eduardo Ferreira de Oliveira, Antônio de Assis Brito, Isaac Xavier Daniel Vasconcelos, Paulo Cesar Botelho, Milena Anunciada, and José Vitorino Neto

Fundação Instituto Tecnológico do Estado de Pernambuco – ITEP, Recife – Pernambuco- Brasil

Abstract – The objective of this work is presents a tape and scale calibrator based in international norms that works in analogical and digital methods, showing the constructives aspects, calibration procedures and comparison between analogical and digital methods refering to the error (of indication) of a measuring instrument, repeatibility and reproducibility.

Keywords: calibrator, tape, scale.

1. INTRODUCTION

Actually, exist in the market several kinds of tapes of varied sizes and built in steel tape and natural or synthetic fibe. In Pernambuco (brasilian State), favours mainly to the Brazilian Program of Quality and Productivity in Habitation (PBQPH), it is having a movement on the part of the constructors and the companies to the civil construction for the certification ISO 9000. In this direction, the calibration of tapes and scales are of basic importance for this companies.

Inside of this context, the objective of this work is to present a “tapes and scales calibrator” since the conception of the design until the procedure of calibration the parts analogical and digital of the related callipers.

It will be shown still a comparative study of error of a measuring instrument and repeatibility for each method.

2. CALIBRATION ASPECTS

The calipers was built being based on a German norm [1], a Japanese norm [2] and two Brasilian norms [3-4] that simultaneously took care of all the requirements mainly as for loads to be applied in accordance with the type of tape.:

Therefore, for the development and construction of the calipers, some referring aspects to the calibration of tapes and scales had been taken in consideration being based on the respective norms. They are:

- the calibration of tapes is carried through with the same ones extended and tractioned on a horizontal plain surface, and the traction load will depend of the material and the capacity of the tape, as shown in the table 1;
- the tapes of steel with capacity of measurement lesser or equal to 5m, will have to be tractioned with a load of 2 kgf, what it corresponds approximately 19,5632 N, a time that the acceleration of the gravity in the laboratory is of $(9{,}7815947 \pm 0{,}0000004) m.s^{-2}$ [5];
- the tapes of natural or synthetic fiber, independent of the measuring range, they will have to be tractioned with a force of 1 kgf, what it approximately corresponds the 9,7816 N because of the acceleration of the gravity of the laboratory;
- for the convex rule and narrow tape measure the necessity of load application does not exist during the calibration;
- the tank tape measure, used for the measurement of the depth of liquids in tanks, possess masses that vary between 200 g and 2 kg. These masses are used to traction these tapes;
- the ambient temperature used for this calibration it’s (20 ± 1) ºC, while the relative humidity of air it’s (50 ± 10) % [6].

TABLE 1: Traction force according capacity and material of the tape

Capacity of the tape	Material of the tape	Traction force
≤ 5m	steel	2 kgf
Every capacity	natural or synthetic fiber	1 kgf

3. PROJECT AND RESULTS

In this conception in one exactly calipers we can use at the same time two systems of calibration: analogical and digital one.

3.1 Analogical Method

It consists of comparing the tape or the scale, with a meter-standard tracked to the Brazilian Net Calibration (RBC), using still as standard auxiliary, a graduated magnifying glass with lesser division of 0,1 mm. This part of the calipers has a system for rolling up the tape and another to application of snatch force, as shown in the figure 1.

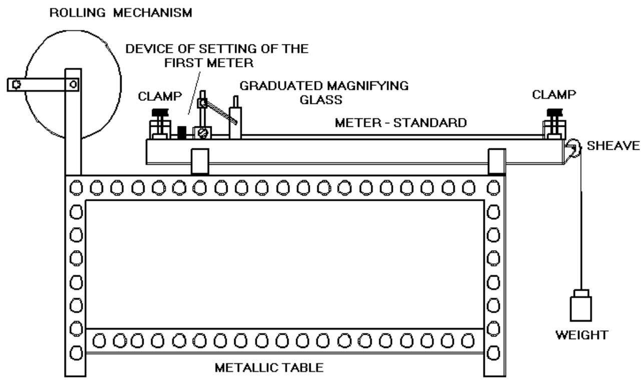

Fig. 1. Calibrator parts (analogical method)

The figure 2 presents the calibration of an analogical tape of steel, with reference T1LIV5, nominal range of 0 - 5m. Its calibration consists of if taking ten points to the long one of the nominal range of the tape, with for example: 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% e 100% of the value of deep of the scale.

Fig 2. Tape Calibration using analogical method

Three series of measurement are carried through, where initially, it through the fixing is fixed the tape, as figure 1, lining up it on the meter-standard as shown in figure 3. After, the load of traction is appllied in function of nominal range as shown the figure 4. Soon after, the point of the tape is compared to be calibrated with the respective point in the meter-standard. The difference between the two points it is measured through the graduated magnifying glass, whose value of the lesser division is of 0,1 mm, being able itself to have an adopted resolution of 0,05 mm.

Fig 3. Analogical calibration process

As the measure range of the standard it is of 1m, has the necessity of measuring meter to meter all the extension of the tape, a time that the errors are accumulating, the error that it have, for example, in the first meter of compared tape, exerts influence over of the remaining extension of the tape.

Fig 4. Mechanism of load application

Tables 2, 3 and 4 present the results of three calibrations carried through in the related tape (T1LIV5) for three different technician of the laboratory (T1, T2 and T3). Analyzing tables 2, 3 and 4, it can be verified that it has a good repeatibility in the analogical method, in function of the training that was given to the technician of the laboratory, as well as of the form and mechanisms of the calipers. About the exactness, the biggest error gotten for this method was of 0,07%, generated for technician T3. It is important to emphasize that the technician T1 and T2 had gotten as bigger error of exactness 0.06%, practically all had gotten the same magnitude of maximum error.

The Figure 5 presents the curves of correction gotten of the calibration of the tape carried through each one of the technicians, using the analogical system. It can be verified that three curves practically possess the same behavior until point 4000 mm, what allows to evidence the quality of the considered service, mainly in that if relates to the stability of the equipment and to the correct use of the procedure technician developed in the scope of this project.

The biggest difference gotten in the correction was of 0,53 mm, practically half of a division of the tape and was evidenced of the calibrations carried through for the technician T1 and T2 in the point of 5000 mm, as shown in figure 5.

TABLE 2: Calibration accomplished for technician T1

SMP (mm)	SMC(mm)			AVERAGE (mm)	CORRECTION (mm)
	X1	X2	X3		
500,00	499,70	499,70	499,70	499,70	0,30
1000,00	1000,00	1000,00	1000,00	1000,00	0,00
1500,00	1499,80	1499,80	1499,80	1499,80	0,20
2000,00	1999,80	1999,80	1999,80	1999,80	0,20
2500,00	2500,00	2500,00	2500,00	2500,00	0,00
3000,00	3000,40	3000,40	3000,40	3000,40	-0,40
3500,00	3500,50	3500,50	3500,50	3500,50	-0,50
4000,00	4000,80	4000,80	4000,80	4000,80	-0,80
4500,00	4501,00	4501,00	4501,00	4501,00	-1,00
5000,00	5001,30	5001,30	5001,30	5001,30	-1,30

Ambient temperature: (19,8±0,2)ºC
Relative humidity of air: (53,6±3,1)%
Biggest error of exactness: 0,06%
Lesser error of exactness: 0
Biggest error of repeatibility: 0
Lesser error of repeatibility: 0

SMP: Measuring system standard
SMC: Measuring system to calibrating

TABLE 3: Calibration accomplished for technician T2

SMP (mm)	SMC(mm)			AVERAGE (mm)	CORRECTION (mm)
	X1	X2	X3		
500,00	499,70	499,70	499,70	499,70	0,30
1000,00	999,90	999,90	999,90	999,90	0,10
1500,00	1499,70	1499,70	1499,70	1499,70	0,30
2000,00	1999,55	1999,55	1999,55	1999,55	0,45
2500,00	2499,90	2499,95	2499,95	2499,93	0,07
3000,00	3000,30	3000,40	3000,40	3000,37	-0,37
3500,00	3500,30	3500,40	3500,40	3500,37	-0,37
4000,00	4000,60	4000,70	4000,70	4000,67	-0,67
4500,00	4500,60	4500,70	4500,70	4500,67	-0,67
5000,00	5000,70	5000,80	5000,80	5000,77	-0,77

Ambient temperature: (20,1±0,3)ºC
Relative humidity of air: (50,0±2,7)%
Biggest error of exactness: 0,06%
Lesser error of exactness: 0,003%
Biggest error of repeatibility: 0,003%
Lesser error of repeatibility: 0

TABLE 4: Calibration accomplished for technician T3

SMP (mm)	SMC(mm)			AVERAGE (mm)	CORRECTION (mm)
	X1	X2	X3		
500,00	499,65	499,65	499,65	499,65	0,35
1000,00	999,85	999,85	999,85	999,85	0,15
1500,00	1499,55	1499,55	1499,55	1499,55	0,45
2000,00	1999,30	1999,30	1999,30	1999,30	0,70
2500,00	2499,60	2499,60	2499,60	2499,60	0,40
3000,00	3000,10	3000,10	3000,10	3000,10	-0,10
3500,00	3500,15	3500,15	3500,15	3500,15	-0,15
4000,00	4000,55	4000,55	4000,55	4000,55	-0,55
4500,00	4500,70	4500,70	4500,70	4500,70	-0,70
5000,00	5000,90	5000,90	5000,90	5000,90	-0,90

Ambient temperature: (20,6 ± 0,2)ºC
Relative humidity of air: (46,8± 2,8)%
Biggest error of exactness: 0,07%
Lesser error of exactness: -0,003%
Biggest error of repeatibility: 0
Lesser error of repeatibility: 0

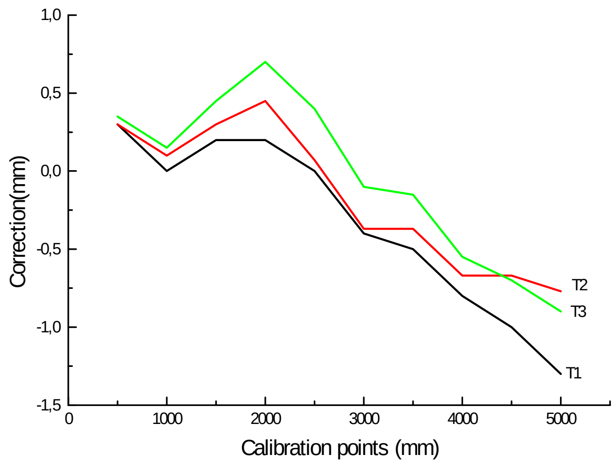

Fig 5. Comparison enters the correction curves considering the calibration by the analogical method carried through for the three technicians.

3.2 Digital Method

In this part of the calipers, an electronic pointer of position is fixed to the base of the calipers, as shown in the figure 6. The pointer is on an electronic panel that besides presenting the indication of the reading, has set-point and memory.

In the same way that in the analytical method, the calibration is carried through meter the meter. However, using the digital method, a resolution is had of 0,005 mm. The positioning is carried through manually and the reference is through a line marked in acrylic plate, as shown in figure 7. The application of the traction load of the tape is accomplished in an accurately identical form to the analogical method.

Fig. 6. Tape calibration using digital method

Fig. 7. Line of reference of the calipers

The analytical method, had been repeated the same conditions of calibration of the tape using the same technicians (T1, T2 and T3) , the same ambient control, the same tape (T1LIV5), varying only the method.

For the digital method, verifying tables 5, 6 and 7, an error of repeatability varying of 0,001% a 0,055% is evidenced what already was waited, mainly for the sensitivity of the equipment for the related calibration. On the other hand, it has practically the same percentile of maximum error of exactness verified in the three calibrations, using the digital method that it's around 0,060%, what it characterizes acceptable values, also becoming the appropriate method for calibration of tapes.

The figure 8 presents the curves of correction gotten of the calibration of the tape, using the digital method. It can be evidenced that until the point of 3000 mm, it has a similar behavior between the three curves. The biggest difference gotten in the correction was 1,426 mm, occured in the calibrations carried through for technician T1 and t2, referring to the point of 5000 mm.

As it can be perceived, a similarity between the curves exists, what it characterizes the reproducibility of the calibrations. On the other hand, the variations gotten individually in the calibrations are very low, characterizing the repeatability of the values gotten for the activities that considers the method.

TABLE 5: Calibration accomplished for technician T1

SMP (mm)	SMC(mm)			AVERAGE (mm)	CORRECTION (mm)
	X1	X2	X3		
500,000	499,810	499,710	499,745	499,755	0,245
1000,000	1000,190	999,900	1000,035	1000,042	-0,042
1500,000	1499,940	1499,575	1499,775	1499,763	0,237
2000,000	1999,595	1999,395	1999,660	1999,550	0,450
2500,000	2499,860	2499,655	2499,880	2499,798	0,202
3000,000	3000,455	3000,105	3000,425	3000,328	-0,328
3500,000	3500,380	3500,175	3500,590	3500,382	-0,382
4000,000	4000,760	4000,615	4000,980	4000,785	-0,785
4500,000	4500,975	4500,805	4501,205	4501,995	-0,995
5000,000	5000,925	5000,965	5001,405	5001,098	-1,098

Ambient temperature: (21,0±0,2)ºC
Relative humidity of air: (47,4±2,6)%
Biggest error of exactness: 0,049%
Lesser error of exactness: -0,004%
Biggest error of repeatability: 0,029%
Lesser error of repeatability: 0,009%

TABLE 6: Calibration accomplished for technician T2

SMP (mm)	SMC(mm)			AVERAGE (mm)	CORRECTION (mm)
	X1	X2	X3		
500,000	499,590	499,640	499,865	499,698	0,302
1000,000	1000,010	1000,120	1000,140	1000,090	-0,090
1500,000	1499,750	1499,935	1499,820	1499,835	0,165
2000,000	1999,575	1999,900	1999,640	1999,705	0,295
2500,000	2499,890	2500,075	2499,790	2499,918	0,082
3000,000	3000,430	3000,355	3000,040	3000,275	-0,275
3500,000	3500,355	3500,285	3500,190	3500,277	-0,277
4000,000	3999,435	3999,520	3999,540	3999,498	0,502
4500,000	4499,570	4499,610	4499,660	4499,613	0,387
5000,000	4999,685	4999,695	4999,635	4999,672	0,328

Ambient temperature: (19,5±0,2)ºC
Relative humidity of air: (53,7±2,7)%
Biggest error of exactness: 0,060%
Lesser error of exactness: 0,003%
Biggest error of repeatability: 0,055%
Lesser error of repeatability: 0,001%

TABLE 7: Calibration accomplished for technician T3

SMP (mm)	SMC(mm)			AVERAGE (mm)	CORRECTION (mm)
	X1	X2	X3		
500,000	499,710	499,550	499,795	499,685	0,315
1000,000	999,770	999,675	1000,005	999,817	0,183
1500,000	1499,515	1499,085	1499,735	1499,445	0,555
2000,000	1998,970	1998,700	1999,515	1999,062	0,938
2500,000	2499,450	2498,820	2499,620	2499,297	0,703
3000,000	3000,015	2999,110	2999,965	2999,697	0,303
3500,000	3500,080	3498,920	3499,985	3499,662	0,338
4000,000	4000,260	3999,070	4000,395	3999,908	0,092
4500,000	4500,475	4499,045	4500,445	4499,988	0,012
5000,000	5000,660	4999,010	5001,420	5000,363	-0,363

Ambient temperature: (19,9±0,2)ºC
Relative humidity of air: (46,6±2,6)%
Biggest error of exactness: 0,063%
Lesser error of exactness: 0
Biggest error of repeatability: 0,049%
Lesser error of repeatability: 0,030%

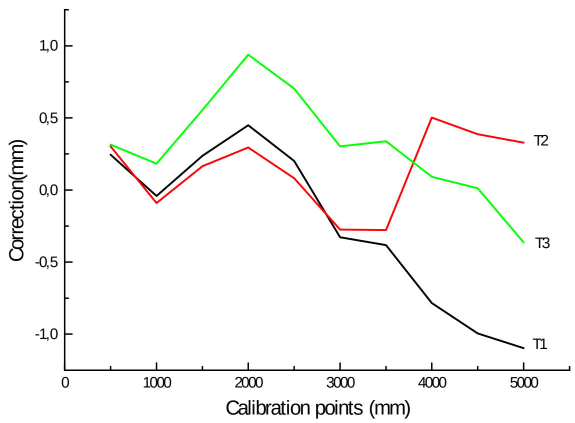

Fig 8. Comparison enters the correction curves considering the calibration by the digital method, accomplished for the three technician.

3.3 Comparative study between the two methods related to the correction

One another sufficiently interesting result that was gotten through the comparison between the two methods, it's about the detected similarity of result when it is overcome the same mensurand, the same technician and the same ambient conditions, varying only the calibration method.

Being overcome as example the calibrations carried through for technician T3, using the analogical method (table 4) and the digital method (table 7), can be gotten the graph presented in figure 9.

Analyzing the graphical related, it verifies that technician T3 when calibrating the cited tape in the two methods got curves of correction with practically identical behaviors, what it evidences a trustworthiness of the equipment as to the fidelity of the used methodology of calibration. In each interval of calibration it has one same trend of behavior for both the curves. The biggest difference of joined correction was 0,712 mm, referring to the point of 4500mm.

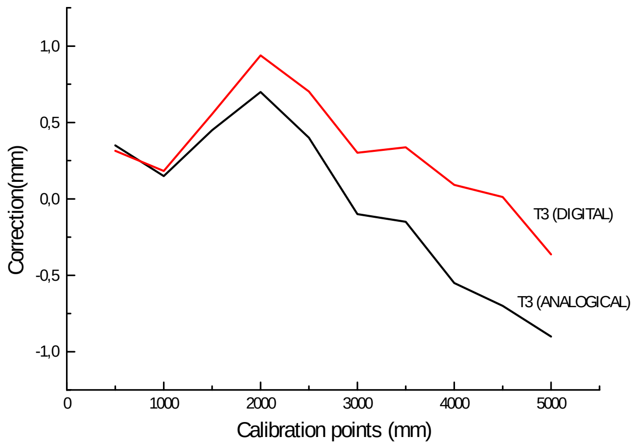

Fig 9. Comparison between the analogical and digital methods, using the calibrations accomplished by technician T3.

4. CONCLUSIONS

One evidence that the calipers of tapes and scales developed in the scope of this work has repeatibility throughout all its nominal band.

As it can be verified through figure 2, the analogical and digital methods could be used at the same time by two different operators, one in each side of the calipers, presenting practically the same error of exactness, both the methods.

Using the digital method, it is eliminated inherited uncertainty (type b) of the graduated magnifying glass that is 0,014 mm.

Although to have itself proven a bigger efficiency of the digital calipers in relation to the analogical one, this last one continuously will be used in the set, for inside presenting values of exactness and repeatibility of the tolerable limits for calibration of tapes. .

The average time of calibration of the tape presented in this work, using the analogical method is of approximately 48 minutes, while through the digital method, approximately has an average time of 52 minutes, what means that the difference of time between the two methods practically does not exist.

Finally, one better repeatibility in the analogical method can be evidenced, what it can be justified by one better adjustment and setting of its mechanical components. However, both the methods present repeatibility inside of the acceptable standards for the calibration of tapes and scales.

REFERENCES

[1] DIN 866, Deutsche Norm, *"Alleinverkauff Der Durch Beuth"*, Verlag GmbH, Berlim, 1983.

[2] JIS B 7522, Japanese Industrial Standart, "*Steel Tape Measures*", 1993.

[3] NBR 10123, Brasilian Norm, "*Trena de fita de aço*", 1987.

[4] NBR 10124, Brasilian Norm, "*Trena de fita – fibra natural ou sintética*", 1987.

[5] M. A. Sousa, "Rastreamento dos Padrões Metrológicos Locais de Força e Pressão", Relatório do Observatório Nacional ao ITEP, December 2002.

[6] - NBR 6165, Brasilian Norm, "*Temperatura de referência para medições industriais de dimensões lineares – Padronização*".

Authors:
José Eduardo Ferreira de Oliveira (jefo@itep.br) *
Antônio de Assis Brito
Isaac Xavier *
Daniel Vasconcelos (daniel@itep.br) *
Paulo Cesar Botelho *
Milena Anunciada (milena@itep.br) *
José Vitorino Neto (vitorino@itep.br)

* Fundação Instituto Tecnológico do Estado de Pernambuco – ITEP (*Mechanical Metrology Laboratory*)
Av. Prof. Luiz Freire, 700 - Cidade Universitária – Recife – Pernambuco – Brazil
CEP: 50740-540
Phone: 00 55 81 3272-4238
Fax: 00 55 81 3271-4590