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Double flank roll testing machines intercomparison for worm and worm gear

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Abstract

Roll testing is the most direct way and simple method of checking the functional accuracy of the gear by means of the geometric and rolling parameters obtained in the test. Nevertheless, for the time being there is no standard calibration procedure which could be applied to this type of rolling testers. In spite of trying to reproduce the tests in the three double flank roll testers under the same testing conditions and procedure, big variations in the results obtained were detected. This demonstrates the need to create a standard which could give a unique trazability procedure for this kind of tests and their tester's calibration.

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Keywords: gear; double flank roll testing; radial composite inspection.

1. Introduction

The term accuracy is derived from the fact of repeating a number of tests under the same test conditions without obtaining identical results. There are different factors contributing to the diversity of the results obtained such as the operator, the measurement equipment used and the calibration process. In the introduction of the standard UNE66543, it is stated that one of the main targets of laboratory intercomparisons is "establishing the effectiveness and the possibility of comparing new testing methods, assuring the previously established methods".

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In this work it is presented the intercomparison of double flank rolling tests for worm and worm gear carried out in three different machines located in three different laboratories (University of Zaragoza, gear's manufacturer facilities and gear's user, see figure 1). As for the time being there are neither calibration nor standard verification procedures available for this type of machines, the analysis done in this paper tries to determine the coincidence degree of the results obtained in the three different equipment under the same test conditions.

Fig.1. Double flank roll tester for worm – worm gear

2. Double flank roll test. Parameters

Nowadays there is a great variety of automatic verification techniques for gears. Among all of them, roll testing are the most direct way of verifying the quality of a gear due to the fact that the parameters obtained in these tests are clearly representative of the future working conditions of the gear. Despite the single flank roll test gives more information, the double flank roll test is broadly extended within the industry due to its lower cost and simplicity.

2.1. Double flank roll test principle

In the radial composite inspection, the test gear and a master gear of higher accuracy grade are rolled against each other without backlash being both meshed at a centre distance lower than the nominal (figure 2). A force acting in the radial direction ensures that left and right-hand flanks of the gears always remain in simultaneous contact. As result the curve of centre distance variations a" within one revolution of the test gear is generated determining on this way the accuracy grade of the test gear.

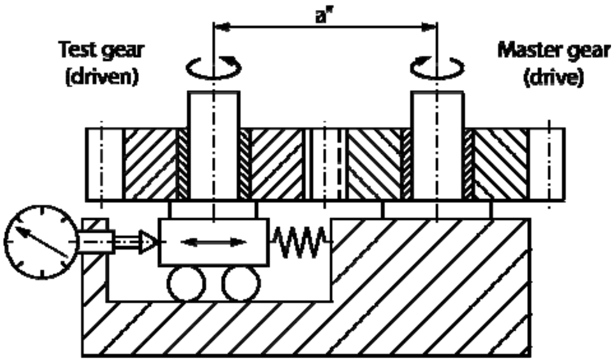

Fig. 2. Double flank roll test principle

2.2. Radial composite deviation parameters

The following radial composite deviation parameters could be defined (figure 3) derived from the variation of the gears centre distance a" within one revolution of the test gear:

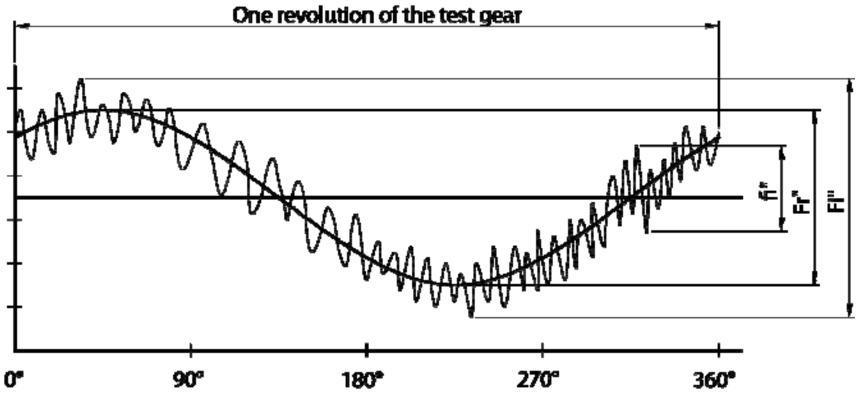

Fig. 3. Radial composite deviation parameters

- Double flank rolling deviation Fi": Fi" is the difference between the maximum and minimum values of the working centre distance, a", which occurs during a radial (double flank) composite test.
- Double flank rolling tooth-to-tooth deviation fi": fi'' is the maximum value of the radial composite deviation corresponding to one pitch, 360°/z, during one complete cycle of engagement of all the product gear teeth.
- Radial Runout Fr'': the value of radial runout of the gear is the difference between the maximum and the minimum radial distance from the gear axis as observed by removing the short-term or undulation pitch deviations and analysing the long-term sinusoidal wave form.

Once the double flank roll test is carried out, a sinusoidal graphic is obtained including a low frequency component due to the runout and a high frequency component representing the quality of the gear. In order to have these values in a separate way, the data obtained in the test are decomposed by means of the Fourier transform (figure 4) defining in this way the runout effect and tooth profile generation respectively.

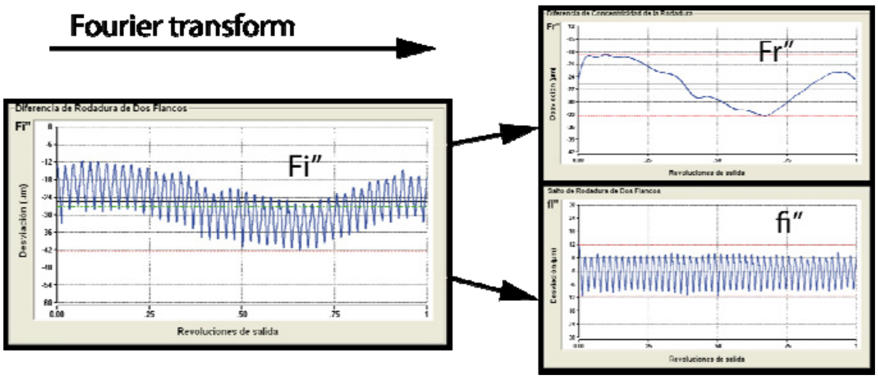

Fig. 4. The Fourier transform and Radial composite deviations

3. Experimental characterization

In order to guarantee the correct tests intercomparison, the test procedure was done according to the standard UNE 66543 where documentation, instructions and statistic planning are stated. So that the measurements will be always made in the same way, the measuring method should be standardized by means of a written procedure which will describe how to carry out the measurements.

3.1. Test equipment

Three double flank roll testers located in three different laboratories are used in the tests explained in this paper:

- Roll tester A: the first machine is located in an elevator's company laboratory and it is used for verification of gears in the incoming inspection area.
- Roll tester B: the second machine belongs to a gear manufacturer who uses the tester to verify the quality of the gears as final inspection.
- Roll tester C: the third machine is located in the metrology laboratory of the Design and Production department of the University of Zaragoza where the tester was recently calibrated under internal procedure.

3.2. Type and size of gears

Due to the different existing types and geometries of gears, the roll testers are normally customized to the specific gear to be inspected. On these grounds, double flank roll testers for worm – worm gear set were used in this work. Table 1 shows the main parameters of the gears verified and their accuracy grades. The gear models were selected for the tests due to their consideration as high runners, biggest production quantities in the gear's manufacturer production.

Table 1. Test gear parameters

Test	Relation (i)	Master gear	Master gear diameter (mm)	Test gear	Test gear diameter (mm)	Module	Accuracy grade	Accuracy (µm)
Type 1	47/2	Worm	Ø60	Worm gear	Ø280	6	6 - 10	30-110
Type 2	55/2	Worm	Ø50	Worm gear	Ø230	4	6 - 10	30-110
Type 3	60/1	Worm	Ø40	Worm gear	Ø220	4	6 - 10	30-110

3.3. Test conditions

The rolling tests were carried out with three different roll testers located in three different laboratories and various operators. Thus, a common test procedure was established focusing on a minimization of the test results dispersion. Besides the use of the standards AGMA 915 and AGMA 935, the recommendations regarding test conditions and equipment calibration, the following test parameters were fixed to standardize the test conditions.

- Test start: all the tests will begin from the same point (same tooth) in order to guarantee the same measurement.
- Speed: the measurement will start in the test when the worm will reach a constant speed of 20 rpm and will end once a complete cycle of engagement of all the product gear teeth at constant speed of the worm gear is finished.
- Rotation: the tests will be always done in the same rotation direction (clockwise or anticlockwise) according to the worm and worm-gear position.
- Temperature: the temperature of the laboratory will be controlled to 20 ± 0'5 °C.

4. Results

So that reliable test results could be obtained, five test repetitions of four different worm gears described in chapter 3.2 were carried out, starting always from the same point and with identical rotation direction. On this way, there will be four rolling tests for each gear size tested, assuring if there is any influence on the result derived from the variation of the transmission ratio.

The data acquisition table used during the testing phase is explained in the Table 2.

Table 2. Data acquisition table

Roll tester number:				Date:
Data Worm:		Data Worm gear:		
Speed:		Rotation:		Temperature:
Test	Hour	Fi” (µm)	Fr” (µm)	fi” (µm)
1				
…				
5				

Once all the tests are finished and the data have been captured, the information is sorted. The results obtained in the test type 1 for first the worm gear sample (transmission ration 47/2) could be seen in the Table 3.

Table 3. Test type 1 (transmission ration 47/2) results of worm gear number 1

Type 1 (47/2)	Fi” (µm)			Fr” (µm)			fi” (µm)		
Worm gear 1	Roll tester			Roll tester			Roll tester		
Repetition	A	B	C	A	B	C	A	B	C
1	35	78	48	9	52	22	28	40	30
2	32	75	46	8	49	19	26	34	33
3	34	75	48	8	48	20	28	31	35
4	32	76	48	8	51	20	26	36	33
5	33	75	47	8	49	21	27	34	32
Max	35	78	48	9	52	22	28	40	35
Min	31	75	46	8	48	19	26	31	30
Range	4	3	2	8,2	4	3	2	9	5
Mean	33,0	75,8	47,4	1	49,8	20,4	27	35,0	32,6
Standard deviation	1,58	1,30	0,89	0,45	1,64	1,14	1,00	3,32	1,82
Mean range	42,8			41,6			8,0		

The same data shown in the Table 3 could be represented in a graph (Figure 5) where maximum and minimum output values obtained in each roll tester together with the difference between the average values per roll tester are shown.

The value included in the last row of the Table 3 (mean range) represents the range calculation of the average measurement per roll tester, being this value the key indicator of the intercomparison analysis carried out in this paper.

Following the same test procedure with all worm gears, the results obtained in the type 1 (transmission ratio 47/2), type 2 (55/2) and type 3 (60/1) tests could be seen in the Tables 4, 5 and 6 respectively.

Test Type 1 (transmission ratio 47/2):

Table 4. Test Type 1 results (transmission ratio 47/2)

		Fi” (µm)			Fr” (µm)			fi” (µm)		
		Roll tester			Roll tester			Roll tester		
	Type 1 (47/2)	A	B	C	A	B	C	A	B	C
Worm gear 1	Mean 1	33,0	75,8	47,4	8,2	49,8	20,4	27,0	35,0	32,6
	Standard dev. 1	1,58	1,30	0,89	0,45	1,64	1,14	1,00	3,32	1,82
	Mean range 1	42,8			41,6			8,0		
Worm gear 2	Mean 2	43,2	17,7	50,7	17,6	7,3	20,7	28,8	13,3	43,3
	Standard dev. 2	3,63	0,58	0,58	0,55	0,58	0,58	3,49	2,89	1,53
	Mean range 2	33,0			13,3			30,0		
Worm gear 3	Mean 3	56,4	35,3	74,7	31,6	11,7	37,0	27,6	24,7	58,3
	Standard dev. 3	1,52	0,58	1,53	0,89	0,58	1,00	2,88	0,58	0,58
	Mean range 3	39,3			25,3			33,7		
Worm gear 4	Mean 4	55,8	21,0	71,3	37,4	11,0	42,3	28,2	12,0	36,3
	Standard dev. 4	4,76	1,73	0,58	3,91	1,73	0,58	0,45	0,00	0,58
	Mean range 4	50,3			31,3			24,3		

a
b
c
d

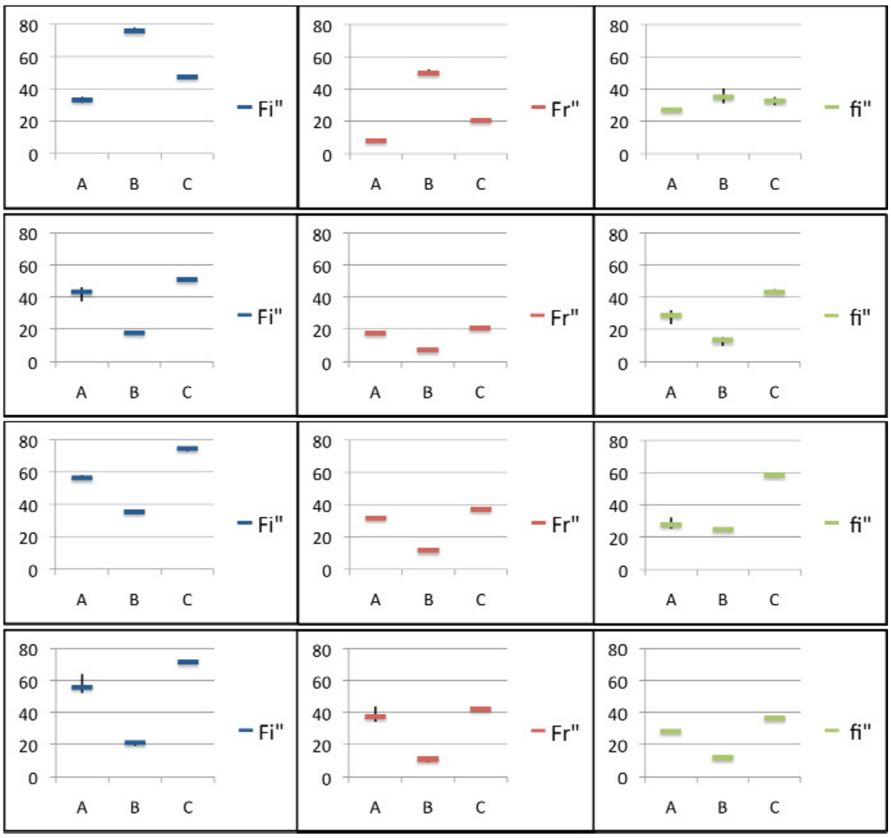

Fig. 5. Results of test type 1 (transmission ration 47/2): (a) Worm gear 1; (b) Worm gear 2; (c) Worm gear 3; (d) Worm gear 4.

Test Type 2 (transmission ratio 55/2):

Table 5. Test Type 2 results (transmission ratio 55/2)

		Fi" (µm)			Fr" (µm)			fi" (µm)		
		Roll tester			Roll tester			Roll tester		
	Type 2 (55/2)	A	B	C	A	B	C	A	B	C
Worm gear 1	Mean 1	82,2	26,8	53,0	36,0	16,8	24,0	55,8	13,6	38,2
	Standard dev. 1	3,56	3,27	0,71	0,00	2,77	3,16	1,30	1,52	0,84
	Mean range 1	56,0			19,2			42,2		
Worm gear 2	Mean 2	64,0	46,3	58,8	24,0	20,7	15,7	47,8	28,7	49,0
	Standard dev. 2	0,82	2,52	1,00	0,00	2,08	1,53	1,26	0,58	1,73
	Mean range 2	17,7			8,3			20,3		
Worm gear 3	Mean 3	103,0	45,0	63,0	61,0	33,7	38,7	51,5	13,3	33,0
	Standard dev. 3	1,41	6,24	0,00	1,41	8,14	1,15	0,71	0,58	2,00
	Mean range 3	58,0			27,3			38,2		
Worm gear 4	Mean 4	84,0	56,0	59,0	39,8	38,0	37,0	57,0	27,7	33,7
	Standard dev. 4	7,87	5,20	0,00	3,50	4,00	1,00	9,83	0,58	1,53
	Mean range 4	28,0			2,8			29,3		

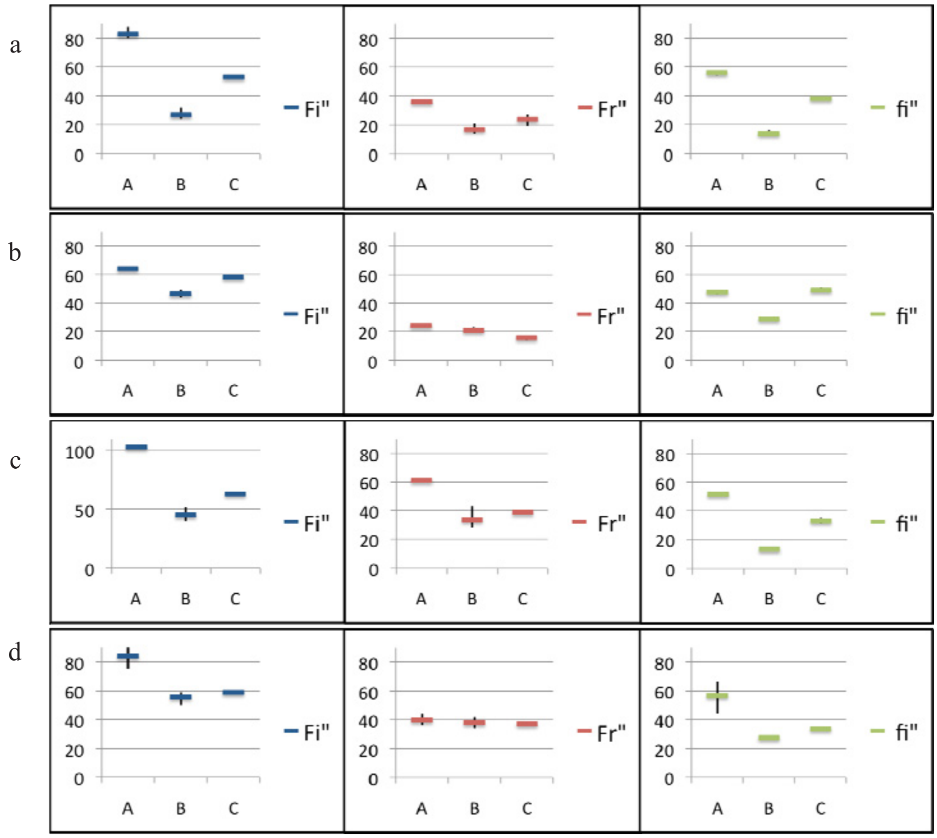

Fig. 6. Results of test type 2 (transmission ration 55/2): (a) Worm gear 1; (b) Worm gear 2; (c) Worm gear 3; (d) Worm gear 4.

Test Type 3 (transmission ratio 60/1):

Table 6. Test Type 3 results (transmission ratio 60/1)

		Fi” (µm)			Fr” (µm)			fi” (µm)		
		Roll tester			Roll tester			Roll tester		
	Type 3 (60/1)	A	B	C	A	B	C	A	B	C
Worm gear 1	Mean 1	27,4	-	53,3	16,8	-	27,3	12,6	-	32,3
	Standard dev. 1	0,89	-	3,79	0,45	-	3,79	0,55	-	0,58
	Mean range 1	25,9			10,5			19,7		
Worm gear 2	Mean 2	38,0	26,3	39,0	17,8	17,7	16,0	22,2	12,7	25,0
	Standard dev. 2	1,22	2,31	2,65	0,45	2,08	3,46	0,45	0,58	0,00
	Mean range 2	12,7			1,8			12,3		
Worm gear 3	Mean 3	28,0	32,0	58,3	14,6	19,7	23,7	17,8	15,7	38,3
	Standard dev. 3	1,22	0,00	2,08	0,89	0,58	1,53	2,49	0,58	0,58
	Mean range 3	30,3			9,1			22,7		
Worm gear 4	Mean 4	47,0	26,3	45,0	23,6	15,3	19,7	25,0	12,3	31,7
	Standard dev. 4	5,66	0,58	1,00	5,41	0,58	1,53	0,00	0,58	6,66
	Mean range 4	20,7			8,3			19,3		

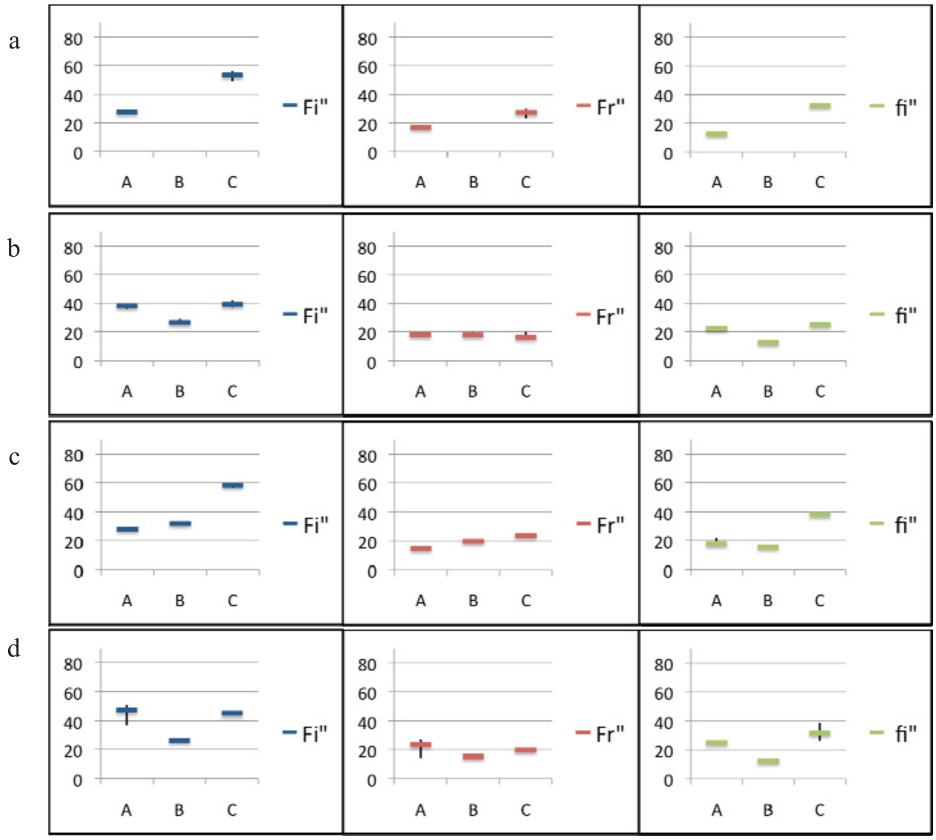

Fig. 7. Results of test type 3 (transmission ration 60/1): (a) Worm gear 1; (b) Worm gear 2; (c) Worm gear 3; (d) Worm gear 4.

5. Conclusions

The first target of this paper was obtaining reliable testing results out of a different range of double flank roll testers for worm and worm gear and this aim was clearly achieved. –In the near future a complete statistical analysis of the tester range will be accomplished.

It could be clearly observed that despite the assurance of identical test conditions during the tests, there is big difference among the results obtained in the three roll testers. This will imply that the quality of the tested gear could be different depending on the roll tester used. Therefore, there is no guarantee regarding the real value and the tests could be considered only as a method for partial validation of the gear's quality.

The great number of error sources together with a lack of standards that could provide a standard traceability procedure are generating this situation. In fact, only a few recommendations regarding test procedure and calibration of the equipment could be found in the standards There is neither certified laboratories to calibrate the testers nor a national master which could assure the measurements traceability.

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