IMPLEMENTING PARTICLE COUNTER CALIBRATION PER ISO 11171-1999

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ABSTRACT

Counting solid particles in oil is one important indicator of machine condition. ISO 11171-1999 provides a vehicle for objective particle counter performance verification since most important instrument parameters are measured and verified. Most importantly the standard sets values to be met for acceptable instrument performance.

It is the complexity of these test procedures, which make it difficult to implement this standard. Manufacturers certify that their instrument meet ISO 11171 requirements but stop short of providing detailed documentation. ISO 11171 results of five different models instruments are presented. Only one of the five instruments passed all ISO 11171 performance criteria.

INTRODUCTION

The need for a standardized means of measuring particles in fuels, lubricants and power fluids has been acknowledged for many years. Beginning in the early 1960s with the focus on the evolving aerospace technology, the benefits of reducing and quantifying contamination in mechanical devices was identified. The direct relation of hydraulic system cleanliness to system life, durability and functionality has been recognized by designers. More attention is now paid during the system design phase to include high efficiency filters and in some cases sensor to detect chips or measure contamination levels in working fluids. This permits the monitoring of fluids and provides a signal for preventive maintenance action. Such actions include filter element change, fluid change or perhaps replacement of other machine components.

The economic aspects of “clean” machine operation have long been overlooked, mainly because the benefits from proactive maintenance are difficult to be correlated immediately and directly with capital equipment savings and loss of productivity.

The main objectives of equipment and facility managers, operators and owners are to extend machine life and productivity and to reduce repair and maintenance cost.

The loss of revenue due to downtime, missed delivery schedules and the cost of repairing catastrophic machine failure are greater than the cost for a structured proactive machine maintenance program. Such a program monitors contamination levels; measures the slow deterioration of mechanical components; predicts preventive maintenance requirements; and schedules repairs with minimal interference on productivity, revenue and profit.

Several approaches to machine condition monitoring are used and a variety of machine parameters (operating temperature, pressure, vibration, noise) and machine fluid (lubrication oil, hydraulic and cooling fluids) properties are monitored to determine the health of machinery. Research and experience indicate that analyzing the changes of the mechanical system by monitoring specific machine parameters is not as predictive as using oil analysis. Mechanical systems, which show measurable changes in their operation (vibration, noise, performance) have already been damaged and an accelerating deterioration process has started, which in most cases can only be treated but not cured.

Oil analysis identifies possible failure of machine components at the onset of the deterioration process many hours of operation before the machine reacts and shows failure symptoms in its vibration or noise spectrum.

Counting solid particles in oil is one important indicator of system condition. These particles come from many sources; new oil directly from the barrel; components from the shelf as the system is assembled; ingress through the breather, through the filler cap when makeup oil is added and passed by faulty wiper seals; or created during system operation due to erosion and wear between moving parts. System filters are used to control system cleanliness. A scheduled monitoring program for particles in the lubricant and power fluid of a mechanical systems can be used in conjunction with basic Statistical Process Control (SPC) to identify when a component failure is imminent and repair can be initiated before catastrophic failure occurs. These scheduled repairs minimize productivity interruptions and reduce machine downtime, the cost of cleaning the system and the cost of failed component replacement.

OVERVIEW OF ISO 11171-1999

Until the introduction of ISO 11171 in December 1999 no comprehensive particle counter calibration procedure existed. Previous standards (ISO 4402-1991) left many important instrument performance parameters open for interpretation or referred to manufacturers recommendations.

The new standard provides a vehicle for objective instrument performance evaluation since all important instrument parameter are measured and verified. Most importantly the standard sets values to be met for acceptable particle counter performance.

ISO 11171 in it’s body and attached Annexes A through E addresses:

1) Instrument electronic noise; Annex A.2
   Procedure; Section 3.2 Noise level : no more than 60 counts/min
2) Flow rate of the oil sample through the instrument ; Annex C: 8 flow rates 20% of working flow rate in 10% changes; counts should not deviate more than 5% from counts at working flow rate
3) Particle size resolution of the instrument; Annex D: 10mm Polystyrene Latex Spheres in Mil-H-5606. Annex D describes a procedure to determine instrument resolution, which is cumbersome and elaborate. However, the standard allows the use of an Multi Channel Analyzer to produce a more accurate resolution measurement.
   Resolution limit not to exceed 10%
4) Particle count accuracy; Annex E :
   Use 3 samples of 1.0 mg/L ISO Ultra Fine Test Dust in MIL-H-5606. Compare statistical data to Table 8 and 7 of the standards

5) Coincidence error; Annex B :
Use suspension of 16 concentrations starting with 0% in steps of 10% to 150% from a mother suspension of 100mg ISO UFTD in 1 (one) Liter of MIL-H-5606 hydraulic fluid. The 5% coincidence error is determined graphically from this series of experiments.
6) Size (number) Calibration; Main body of the Standard, Chapter 6 : A suspension of about 2.8 mg ISO Medium Test Dust (MTD) per Liter of MIL-H-5606 is used to determine the electronic threshold setting of the instruments by number of particles counted. For a Primary Calibration standard reference material (NIST SRM2806) must be used to verify the accuracy of the threshold settings. Using NIST SRM 2806 makes the instruments calibration traceable to an official NIST Standard Reference Material which has been optically verified by an independent method in particle number and size

It is the complexity of the ISO 11171 test procedures, which make it difficult to implement this standard with the common user. Some instrument technician and laboratory skills are required to properly handle adjustment of instrument electronics and the preparation of the particle suspensions. Although ISO 11171-1999 is a step in the right direction, it has not yet proven itself as practical method with users. Since the introduction of ISO 11171 in December 1999, Particle counter manufacturers have done very little to simplify access to the critical parts of their instruments allowing less circumstantial performance validation. Responding to the demand of their customers they are now struggling to implement design and operational changes to simplify the use of their instruments to meet ISO 11171. Through out the development of ISO 11171 (1994-1999) manufacturers left it to the users of their instruments, primarily hydraulic filter manufacturers in need of equally well performing instruments, to spearhead the implementation of the new standard.

Some of this complexity can be simplified by semi-automating the ISO 11171 procedures. Spreadsheets have been developed which guide users through all the steps collecting the data and producing the final instrument evaluation results.

ISO MTD / ISO UFTD vs. ACFTD

In addition to the problems relating to particle counter performance, the source for test dust used for filter testing and calibrating particle counters, Air Cleaner Fine Test Dust (ACFTD), disappeared and forced the development and characterization of a new test dust. A project was initiated by the National Fluid Power Association (NFPA), asking the National Institute of Science and Technology (NIST) to characterize ISO Medium Test Dust (ISO MTD) by size and number.

The results of this project are published in reference [1] and confirmed expected [2] differences in the number-size distribution of ACFTD and ISO MTD (NIST traceable SRM 2806). Attempts have been made to explain these differences by referring to different methods used to characterize ACFTD and ISO MTD. However, those attempts cannot explain all the observed differences [3].

In order to connect the past (ACFTD) with the future (ISO MTD) the standard committee had two choices:

1) Maintain the numbers and change the particle size or
2) Maintain the size and change the numbers.

The Committee decided for 1) : Maintain the number and change the size.

This decision required that the "new" particles size is identified to avoid confusion with the "old" size :

μm(c) indicates NIST (c)ertified ISO MTD size
μm corresponds to a size based on ACFT

Table 1 shows that correlation between ACFT and ISO MTD

ISO MTD [μm(c)]	ACFTD [μm]	Cum. # of Particles/μg of dust		Classifiaction
4.0	<1	2176		**ISO 4406-1999**
4.2	1	1752		
4.6	2	1397		
6.0	4.3	653		**ISO 4406-1999**
6.5	**5**	516		*ISO 4406-1991*
9.8	10	143		
13.6	**15**	55.2		*ISO 4406-1991*
14	15.5	51.0		**ISO 4406-1999**
21.2	25	13.3		
24.9	30	7.50		
31.7	40	2.86		
38.2	50	1.29	cal by size	
68	100	0.08	cal by size	

TABLE 1 ISO MTD and ACFTD Particle sizes for the same number of particles/μg of dust

Particle counters are used primarily for two purposes:
1) in an upstream – downstream filter test (ISO 16889) to measure the efficiency of filters retaining particles of specific sizes
2) for quantifying solid particle contamination in fluids

Both applications need reliable accurate counting instruments. Because applications use these measurements differently, adjustments to the reporting method were also required.

In Filter Testing a ratio of upstream cumulative counts to downstream cumulative counts for particles larger or equal of a specific size, is defined as Beta Ratio. Forming the ratio of the counting results eliminates systematic errors in both measurements. Instruments can be "matched" easily by running a constant, stable particle suspension in the filter test rig with no test filter present. Matching two sensors reduces absolute measurements to relative measurements. Since filters are also tested with the same dust or dust with a size distribution close to the calibration size distribution of the particle counters, the error in the Beta Ratio results from particle counters is small. When the decision was made to maintain the particle numbers and adjust the particle size, Beta Ratio, which is reported at specific sizes had to be modified for the "new" (ISO MTD) particle size. Filter manufacturers are now concerned that their customers might interpret the change from a Beta 2 mm =100 (old) to Beta 4.6 mm(c) = 100 (new) as a reduction of filter performance. Reference [4] addresses in details the impact the new nomenclature and definition has on the classification of hydraulic oil and lubricant filters.

Monitoring Particulate Contamination in a system fluid requires an absolute quantification of the number of particles and their size. The hydraulic industry, aerospace industry and the military have used cleanliness classification providing simple guidelines for a variety of applications. ISO 4406-1991 uses ACFTD based 5mm and 15mm particle sizes to describe the cleanliness of fluids. This classification was replaces with ISO 4406-1999 when 4mm(c), 6mm(c) and 14mm(c) were introduced as new classification sizes. 6mm(c) and 14mm(c) were selected so the counts between ACFTD and ISO MTD are approximately the same and the cleanliness classes are maintained. 4mm(c) was added to satisfy requests from many applications for monitoring the large number of small "silt" particles. With the introduction of these new classification sizes the cleanliness classes over all were maintained and the guidelines provided by equipment manufacturers for fluid cleanliness changed in the worst case only by one ISO Cleanliness Class.

ISO 11171-1999 sets generally accepted performance requirements for particle counters. Because particle counters are of different design and concepts, the complex test procedures of ISO 11171 were developed to verify accuracy, reproducibility and reliability of these instruments. By adhering to ISO11171 counting results from particle counters of different model and manufacturer become comparable, even if the detection concepts and instrument designs are different. Most of the particle counters used in the field were developed and manufactured prior to the release of ISO11171-1999 and must be verified with regard to their compliance to ISO 11171-1999.

During the training of instrument service and calibration technicians of a major Instrumentation Service Provider in the procedures of ISO 11171–1999, five particle counters of different make and model were used. These particle counters represent instruments currently used for counting particles in hydraulic fluids and lubricants throughout the industry. All instrument models are listed in the manufacturer's literature to be ISO 11171 compliant.

ISO 11171 calibration procedures were applied to evaluate the performance details of these five particle counters: two laboratory bottle sampling instrument systems and three portable instruments. To avoid unnecessary discussions the instruments are not identified by model and manufacturer but labeled A, B, C, D and E for identification. All instruments were rigorously tested to ISO11171 procedures. No deviation from the required procedure was permitted. The summary of the results from Annex A through E is shown in Table 2.

CONCLUSION

Over all results: 4 of the 5 tested instruments failed ISO 11171 for more than one reason. Instruments A, B, D and E fail the preliminary Instrument check by not meeting the required COVV value of 3%. Repair and optical alignment is required when instruments fail the Preliminary Instrument Check of Annex A. These instruments have their first (smallest) size threshold adjusted below the required 1.5 x noise level. This might be one explanation for their high COVV values.

The same Instruments (A,B,D and E) fail the resolution test (Annex D) indicating problems with optical alignment of the sensors. (Figure 1 and 2)

The Counting Accuracy Test (Annex E) reveals that Instruments A and B fail this test for the 5 mm(c) particles and instruments A, B and D fail for 10 mm(c) particles.

All four failing instruments operate outside of their performance range with the noise interfering with accurate counting. None of the 4 instruments sized and counted 4 mm(c) particles correctly.

Three of the instruments (A, B and D) fail all three minimum performance requirements of ISO 11171 (Annex A: COVV <3% of the Preliminary Instrument Check and the Noise requirement; Annex D: Resolution < 10%; and Annex E: Counting Accuracy for 5mm(c) and 10mm(c) particle sizes)

Instrument E fail Annex A and Annex D but passed Annex E requirements. The only instrument truly meeting ISO11171 requirements is instrument C.

All instruments came from their users with original factory calibration documentation. Two of the instruments (C and E) had certificates identifying them being calibrated to ISO 11171-1999 standards. The other instruments had older calibration certificates based on ISO 4402-1991 and ACFTD. These instruments might require optical alignment and electronic modification to become compliant with ISO11171 requirements.

For fairness it also should be mentioned that Instruments A,B, D and E are of older design, prior to the initiation of ISO 11171. It is possible to refine the design of these instruments by utilizing the advancements in all areas of technology (laser, electronics, noise reduction) to make these instruments compliant with ISO 11171.

Only one instruments of a specific model and manufacturer were tested to ISO 11171 requirements in this study. All statements made in this work are strictly relating to the specific instruments tested. The results should not be extrapolated to other instruments of the same model and manufacturer, which have not been tested to ISO 11171 requirements.

During this study it became apparent that ISO 11171-1999 has several shortcomings that must be addressed in future revisions. The particle counter manufacturers also must accept responsibility for addressing the following concerns: volume accuracy, allowable noise level and the effect of flow rate on counting accuracy. The performance of these parameters fall under instrument design constrains and are therefore the responsibilities of the manufacturer. A common, verifiable statement of conformance to ISO11171-1999 delivered with each new particle counter will establish trace ability to NIST's Standard Reference Material (SRM2806), which many uses desire.

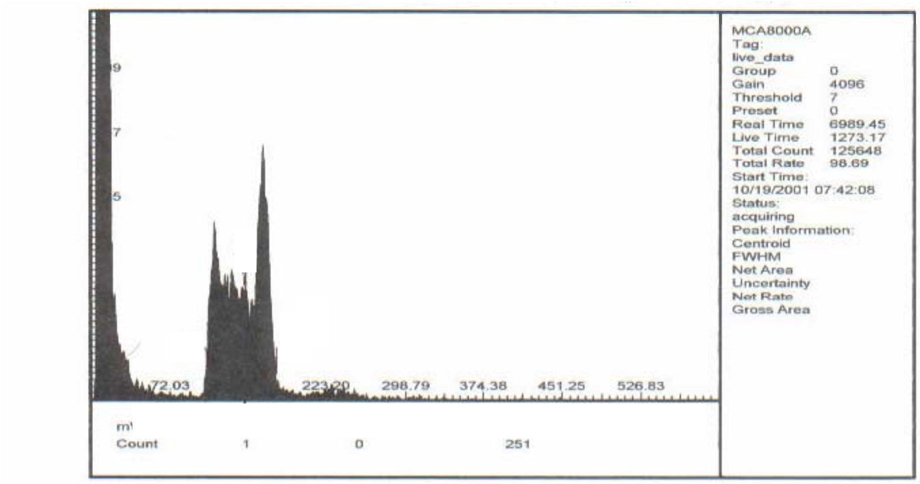

Fig. 1 Resolution of Instrument A $R_L = 22\%$ $R_R = 22\%$

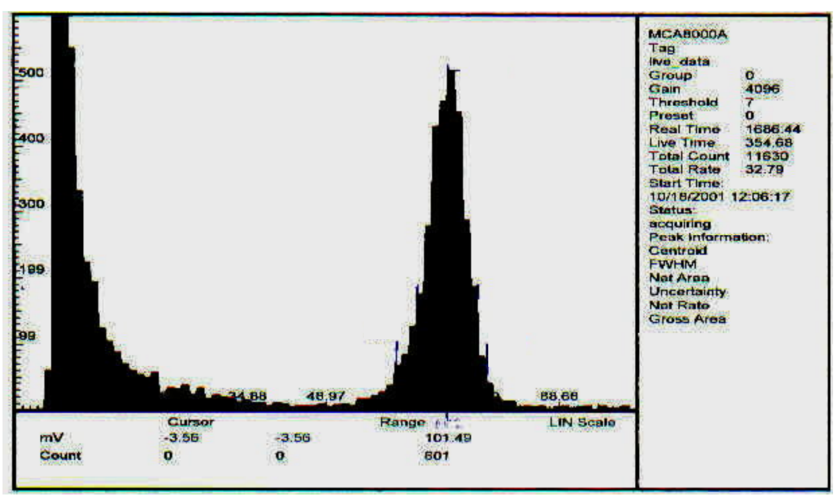

Fig. 2 Resolution of Instrument E $R_L = 11.3\% R_R = 10.2\%$

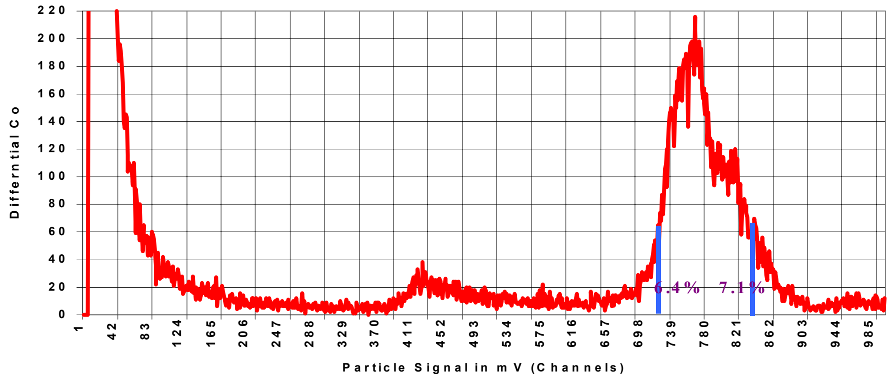

Fig. 3 Resolution of Instrument C R_L = 6.4% R_R = 7.1%

Result Summary ISO 11171-1999 Particle Counter Calibration

Partile Counter Over all Result	Annex A : Preliminary Instrument Check				Annex B: Coincidence			Annex C: Flow Rate Limit		
	Noise [mV]	1.5 x Noise [mV]	Manuf. Smallest Size Channel [mV]	COVv < 3 [%]	0% Manuf. [#Part./mL]	5% Manuf. Calculated	5% [#Part./mL]	Working mL/min	Upper mL/min	Lower mL/min
A Failed	15.00	22.50	17	4.5	10000	5000	3462	60	72	48
B Failed	19.50	29.25	20	6.8	45000	22500	16828	20	16	24
C Passed	10.00	15.00	25	2.1	90000	45000	43435	50	20	70
D Failed	17.00	25.50	22	7.3	45000	22500	14769	50	40	60
E Failed	13.00	19.50	17	4.1	30000	15000	9785	50	40	60

Partile Counter Over all Result	Annex D: Resolution		Annex E: Counting Accuracy					
	Manuf.Res. [%]	10μm PSL [%]	5 [μm(c)] Expected#/mL	Actual#/mL	COV[%] <7.9	10 [μm(c)] Expected#/mL	Actual#/mL	COV[%] <10
A Failed	<10	2	3300 - 4500	4436	8.7	58-220	63	11.2
B Failed	<10	13.2	3300 - 4500	4230	9.3	58-220	76	13.3
C Passed	<10	7.1	3300 - 4500	3854	4.7	58-220	154	6.9
D Failed	<10	17.3	3300 - 4500	4439	7.6	58-220	97	16.8
E Failed	<10	11.3	3300 - 4500	3732	5.9	58-220	190	8.6

Table 2 Summary of ISO 11171-1999 Results

References

[1] Fletcher, Robert et al, " SRM 2806 (ISO Medium Test Dust in Hydraulic Oil); A Particle Contamination Standard Reference Material for the Fluid Power Industry" Fluid/Particle Separation Journal of the American Filtration Society V12 No2 p 80-95, 1999

[2] G. Massbaum, Mikroskopische und Chemische Analysen am Teststaub ACFTD, O+P Oelhydraulik und Pneumatik 29 (1984) Nr. 11, S. 673-678.

[3] Holger T.Sommer "Use of Particle Counters in Condition Monitoring" Society of Tribology and Lubrication Engineers Proceedings of Condition Monitoring, 2001 San Antonio, TX Febr. 2001.

[4] Bensch, L.E. "Impact of Changes to ISO Standards on Filter Performance and Fluid Cleanliness," Fluid Power Journal September-October 1999.