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Hydraulic fluid power — Sample calculations for ISO 11171

Contents

Foreword

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This document was prepared by Technical Committee ISO/TC 131, *Fluid power systems~~ and components~~*, Subcommittee SC 6, *Contamination ~~Control~~control*.

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Introduction

ISO 11171:2022, like its predecessors, retains traceability to the internationally accepted definition of a metre and reports particle size in units of µm(c). The methods for determining data acceptance criteria, coincidence error limit, working flow rate, and resolution remain unchanged, but mathematical calculations and tools were first introduced in ISO 11171:2020 to ensure consistency in terms of how automatic particle counter (APC) calibration curves are created and used. For example, mathematical techniques have been introduced to determine the APC threshold settings used to obtain calibration data and a tool provided to generate calibration curves. Other mathematical equations to estimate the standard error of the calibration, to calculate normalized concentrations for diluted samples, and to calibrate at particle sizes larger than 30 µm(c) were first introduced in 2020. This document uses example calculations that ~~are in full compliance with~~fully conform to ISO 11171.

Hydraulic ~~Fluid Power~~fluid power — Sample ~~calculation~~calculations for ISO 11171

1 Scope

This document shows how to use the normative mathematical ~~equations~~formulae and tools of ISO 11171. Examples are used to demonstrate their use for calibrating automatic particle counters (~~APC~~APCs).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11171, *Hydraulic fluid power — Calibration of automatic particle counters for liquids*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11171~~, *Hydraulic fluid power — Calibration of automatic particle counters for liquids*~~ apply.

ISO and IEC maintain ~~terminological~~terminology databases for use in standardization at the following addresses:

~~IEC Electropedia: available at~~ — ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Example 1: Selection of threshold voltage settings

~~Throughout this technical report, any cited clauses or annexes refer to the corresponding clause or annex in ISO 11171.~~ The method of selecting threshold voltages for particle sizing calibration is specified in ISO 11171~~ clause~~:2022, 6.3~~. This clause~~, which requires that:

— a minimum of 12 different threshold settings be used to ~~constructing~~construct a calibration curve;

— the first (lowest) threshold setting, J, be 1,5 times the threshold noise level of the APC;

— the highest threshold setting, H, corresponds to a particle size of approximately 30 µm(c) or smaller for primary calibrations and ~~must~~corresponds to a size that does not exceed the largest reported particle size that is in conformance with ISO 11171:2022, Annex F, for secondary calibrations; ~~and~~

— intermediate threshold settings be logarithmically spaced such that the value of each channel is K times greater than its preceding channel, where K is a constant defined by Formula (1):

$$K = 10^{(\log H - \log J)/(G-1)} \tag{1}$$

where G is the number of threshold settings used to construct the calibration curve and ~~must be~~is greater than or equal to 12.

This example considers an APC with ~~8~~eight threshold settings that can be adjusted in 1 mV increments. The threshold noise level of the APC was determined to be 5 mV and its manufacturer indicated that 30 µm(c) is expected to correspond to a threshold voltage setting of about 2 600 mV.

The calibration curve will be determined using 12 threshold voltage settings, the minimum number permitted by ISO 11171. Thus, the value of H is 2 600 mV and the value of *G* is 12. The value of *J* is determined by Formula (2):

$$J = 1{,}5 \times 5 = 7{,}5$$

~~$J = 1{,}5 \times 5\ mV = 7{,}5$~~ (2)

Since this APC can only be adjusted in 1 mV increments, the value of *J* is rounded up to 8 mV for calibration. Using the values of *G, H* and *J*, the value of *K* can be calculated by ~~formula~~ Formula (3):

$$K = 10^{(\log H - \log J)/(G-1)} = 10^{(\log(2\,600) - \log(8))/(12-1)} = 1{,}692 \quad (3)$$

The threshold settings for the 10 intermediate channels are set at values corresponding to 1,692 times the value of each preceding channel as shown in Table 1.

Table 1 — Threshold voltage settings for APC in Example 1

Threshold setting number	Calculation	Threshold voltage ~~setting[1]~~setting[a]
1	1,5 ~~x~~ × 5 mV =	8 mV
2	1,692 ~~x~~ × 8 mV =	14 mV
3	1,692 ~~x~~ × 14 mV =	23 mV
4	1,692 ~~x~~ × 23 mV =	39 mV
5	1,692 ~~x~~ × 39 mV =	66 mV
6	1,692 ~~x~~ × 66 mV =	111 mV
7	1,692 ~~x~~ × 111 mV =	188 mV
8	1,692 ~~x~~ × 188 mV =	317 mV
9	1,692 ~~x~~ × 317 mV =	537 mV
10	1,692 ~~x~~ × 537 mV =	908 mV
11	1,692 ~~x~~ × 908 mV =	1 537 mV
12	1,692 ~~x~~ × 1 537 mV =	2 600 mV

~~1~~a Threshold voltage settings rounded off to the nearest mV based upon the capabilities of the APC in the example.

This APC only has the minimum number of channels required in ~~Clause~~ISO 11171:2022, 6.4 (~~8~~eight channels), but ~~Clause~~ISO 11171:2022, 6.3, requires data from ~~12~~twelve or more threshold settings to construct a calibration curve. ~~Clause~~ISO 11171:2022, 6.8, requires that data from at least ~~2~~two different samples be obtained for each of the threshold voltage settings (refer to ~~clause~~ISO 11171:2022, 6.8) and that the channels used for a particular sample be distributed over the entire range to the extent possible. To meet these requirements in this example, ~~8~~eight different threshold settings chosen from the list of ~~12~~twelve can be used for the first sample and different combinations of ~~8~~eight threshold settings used for each of the other two samples.

An example of how to allocate threshold settings among the ~~8~~eight channels is shown in Table 2, where the first column lists the twelve required threshold voltage settings and columns 2, 3~~,~~ and 4 show the channels used to collect data at these settings for the indicated sample. The last column in Table 2 shows the number of samples for which data ~~is~~are obtained for each threshold setting, confirming these requirements have been met.

Table 2 — Allocation of threshold voltage settings among the 8eight channels of the Example 1 APC

Threshold voltage setting mV[1]mV[a]	Channel number corresponding to indicated threshold voltage setting and sample			Number of samples at indicated threshold voltage setting
	Sample A	Sample B	Sample C	
8	1		1	2
14		1	2	2
23	2		3	2
39	3	2		2
66		3	4	2
111	4		5	2
188	5	4		2
317		5	6	2
537	6		7	2
908	7	6		2
1 537		7	8	2
2 600	8	8		2

[1][a] Threshold voltage settings determined in Table 1.

5 Example 2: Evaluating data quality

ClauseISO 11171:2022, 6.6, specifies how to verify the acceptability of particle count data for APC calibration purposes. In brief, the process involves:

— calculation of the total number of particles, N, counted for a given APC channel and sample;;

— calculation of the data quality factor, D_Q, and;

— identification of potential outliers among the data if the D_Q is unacceptable.

This process is used throughout ISO 11171 to ensure the integrity of data used for APC calibration. This example uses a calibration suspension sample analysed as described in ClausesISO 11171:2022, 6.5 and 6.6, using a sample volume, V, of 10 mL ml. Unless otherwise noted, the term “particle concentration” will referrefers to cumulative particle concentration throughout this document. Particle concentrations of 26 068 particles/ml, 25 757 particles/ml, 25 802 particles/ml, 31 771, particles/ml and 25 834 particles/mLml were obtained. The mean particle concentration, $\bar{X}$, for these five counts is 27 046. The mean observed number of particles counted for the five particle counts, X, is given by Formula (4):

$$X = \bar{X}V = 27\,046 \times 10 = 270\,460 \qquad (4)$$

The total number of particles, N, counted for the sample is calculated using Formula (5):

$$N = 5X = 270\,460 \times 5 = 1\,352\,300 \quad (5)$$

This value is greater than 1 000, as required by ISO 11171:2022, 6.6, hence is sufficiently high for calibration purposes.

Using ISO 11171:2022, Table C.2~~ of ISO 11171,~~ and the value of X previously calculated, the maximum allowable D_Q for the data can be determined. Referring to the first two columns of the ~~Table~~table, a value of 270 460 for X corresponds to the first row of the ~~Table~~table, i.e. X greater than or equal to 10 000. The maximum allowable D_Q can be found in the third column, which is used for ~~clauses~~ISO 11171:2022, 6.6, 6.13, B.5, C.9, D.4, D.9, E.6 and F.5. Thus, the maximum allowable D_Q is 11,0 for this example. The value of D_Q, expressed as a percentage, for the data in this example is calculated using Formula (6):

$$D_Q = \frac{X_{max} - X_{min}}{\bar{X}} \times 100 = \frac{31\,771 - 25\,757}{27\,046} = 22{,}24 \quad (6)$$

~~$D_Q = \frac{X_{max} - X_{min}}{\bar{X}} \times 100 = \frac{31\,771 - 25\,757}{27\,046} = 22{,}24$~~

where~~:~~

~~X_{max} is the maximum number of counts observed among the 5 particle counts or 31 771;~~

~~X_{min} is the minimum number of counts observed among the 5 particle counts or 25 757.~~

X_{max} is the maximum number of counts observed among the five particle counts or 31 771;

X_{min} is the minimum number of counts observed among the five particle counts or 25 757.

Since the value of D_Q is greater than the maximum allowable D_Q, the data ~~is~~are unacceptable for calibration purposes and can be examined for possible outliers.

The outlier test parameter, D_0, for the data in this example is calculated using Formula (7):

$$D_0 = \frac{X_{max} - X_{min}}{|X_0 - X_N|} = \frac{31\,771 - 25\,757}{|31\,771 - 26\,068|} = 1{,}05 \quad (7)$$

~~$D_0 = \frac{X_{max} - X_{min}}{|X_0 - X_N|} = \frac{31\,771 - 25\,757}{|31\,771 - 26\,068|} = 1.05$~~

where

~~X_0 is the observed particle concentration of suspected data outlier (either X_{max} or X_{min}), 31 771 particles/mL;~~

~~X_N is the observed particle concentration closest in value to the suspected outlier, 26 068 particles/mL.~~

X_0 is the observed particle concentration of suspected data outlier (either X_{max} or X_{min}), 31 771 particles/ml;

X_N is the observed particle concentration closest in value to the suspected outlier, 26 068 particles/ml.

If the value of D_0 is less than 1,44, as in this example, X_0 can be discarded as a statistical outlier. In ~~example~~ Example 2, D_0 was found to be 1,05, well below 1,44, hence the suspect data point, 31 771, can be discarded as an outlier. The remaining ~~4~~four data points are used to recalculate $\bar{X}$, giving a value of 25 865 particles/~~mL~~ml, which will be used in constructing the calibration curve.

In another example, data from a different channel setting is considered for the same calibration suspension sample analysed in the previous example. For this channel setting, particle concentrations of 810 particles/ml, 802 particles/ml, 800 particles/ml, 805 particles/ml and 803 particles/~~mL~~ml were obtained.

The mean particle concentration, $\bar{X}$, for these five counts is 804. The mean observed number of particles counted for the five particle counts, X, is given by Formula (8):

$$X = \overline{X}V = 804 \times 10 = 8\,040 \quad (8)$$

The total number of particles, N, counted for the sample is calculated using Formula (9):

$$N = 5X = 8\ 040 \times 5 = 40\ 200 \quad N = 5X = 8\ 040 \text{ x } 5 = 40\ 200 \quad (9)$$

This value is greater than 1 000, as required by Clause 6.6 of ISO 11171:2022, 6.6, hence is sufficiently high for calibration purposes.

Using Table C.2 of ISO 11171:2022, Table C.2, and the value of X previously calculated, the maximum allowable D_Q for the data can be determined. Referring to the first two columns of the Tabletable, a value of 8 040 for X corresponds to the second row of the Tabletable, i.e. X greater than or equal to 5 000 but less than 10 000. The maximum allowable D_Q can be found in the third column, which is used for clausesISO 11171:2022, 6.6, 6.13, B.5, C.9, D.4, D.9, E.6 and F.5. Thus, the maximum allowable D_Q is 11,3 for this example. The value of D_Q, expressed as a percentage, for the data in this example is calculated using Formula (10):

$$D_Q = \frac{X_{max} - X_{min}}{\overline{X}} \times 100 = \frac{810 - 800}{804} = 1{,}20 \quad D_Q = \frac{X_{max} - X_{min}}{\bar{X}} \times 100 = \frac{810 - 800}{804} = 1{,}20 \quad (10)$$

where

X_{max} is the maximum number of counts observed among the 5 particle counts or 810

X_{min} is the minimum number of counts observed among the 5 particle counts or 800.

- X_{max} is the maximum number of counts observed among the five particle counts or 810;
- X_{min} is the minimum number of counts observed among the five particle counts or 800.

Since the value of D_Q is less than the maximum allowable D_Q, the data isare acceptable for calibration purposes and can be used in constructing the calibration curve.

6 Example 3: Dilution of samples

To facilitate calibration at small particle sizes, ISO 11171:2022, Annex G of ISO 11171, provides a standardized procedure for the diluting calibration suspensions and ClauseISO 11171:2022, 6.7, specifies a method for normalizing the resultant particle count data. To use this procedure, one needsit is necessary to know the coincidence error limit of the APC and the approximate size of the smallest particles that it can count. In this example, the APC is capable of counting particles as small as 2 µm(c) and has a coincidence error limit, X_A, of 12 713 particles/mLml. The certified particle size distribution of the calibration samples is shown in Table 3.

Table 3 — Certified particle size distribution of calibration sample for Example 3

Certified Particle Size particle size µm(c)	Certified Particle Concentration particle concentration particles/mL ml
2	33 066
3	17 714
4	10 865
5	6 637,0
6	4 210,0
7	2 886,4