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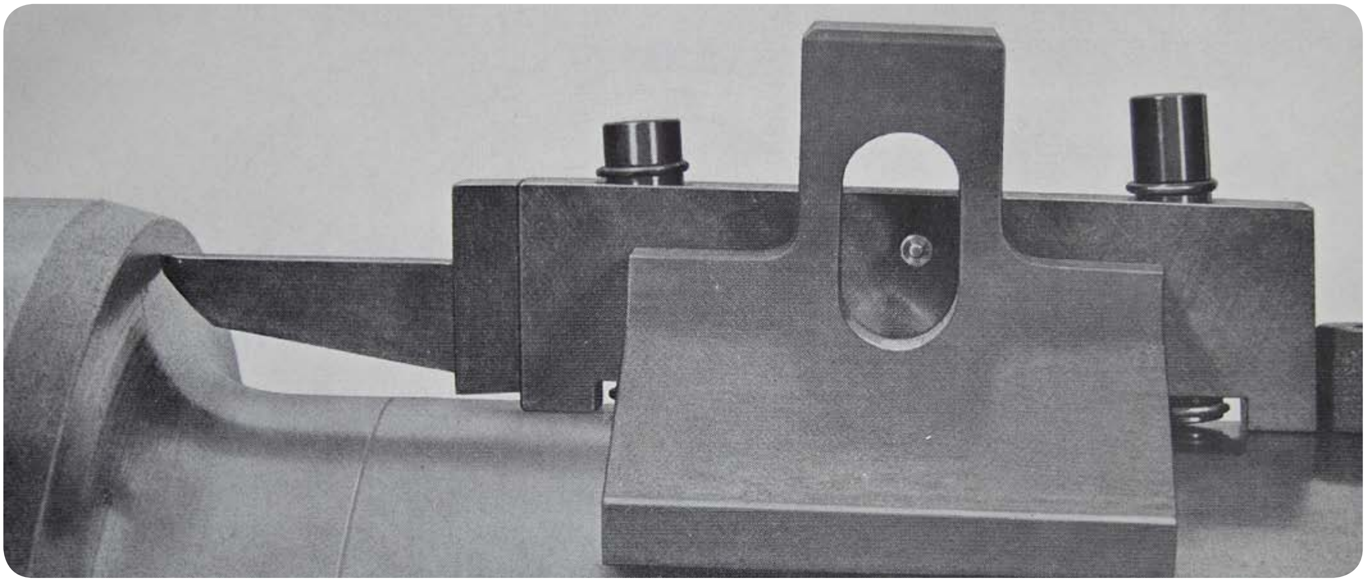
SKF Pulp & Paper Practices



A photograph of the SKF 9205 taper gauge from a 1960s publication.

Don't get rid of your archives!

The archives are the memory of a company. Employees retire, but old documents never have to. Reading them can help you avoid making mistakes that others have made before or reinventing the wheel. Most importantly, they can give insight in to today's situation.

Why does that American paper mill refuse to mount standard SKF spherical roller bearings on its drying cylinders? The archives from the 1970s tell us that they had bearing failures due to ring cracking. This was from a time when SKF supplied bearings with martensitic heat treatment in the USA and ones with bainitic heat treatment in Europe (see *SKF Pulp & Paper Practices issue 7*). The current employees in the mill in question don't know why they only use bearings with case hardened inner rings. They were told to do so by long-retired colleagues.

Why does this mill select bearing clearance class based on a rule of thumb that no longer exists in today's SKF literature? The archives can tell us that the rule was used for fan applications before the 1970s. Further investigation would reveal that an engineer started to use it for other applications and that he was involved in training others. One of the people he trained started to use the rule with speed ratings rather than speed limits and become an "expert". And, so, the error spread.

Even though the archives aren't complete, I still have the chance to access some technical documents from the early 1920s and 1930s. Some consider them obsolete and think they should be removed to make space. This would be a mistake. The cover photograph above, for example, is from a document about the SKF 9205 taper gauge published in 1961. Without our archives, we wouldn't have been able to ascertain that a strange value in a table was the result of an error in an update from the 1980s which was reproduced in subsequent publications. I fear that it won't be so easy to access today's electronic files for such information in future decades.

Regards,
Philippe Gachet
Senior technical consultant
SKF Pulp & Paper global segment

Checking tapered journal geometry (continued)

In the previous issue of SKF Pulp & Paper Practices, I covered checking tapered journal geometry with the imprecise and subjective Prussian blue method. I also wrote about more objective and accurate approaches i.e. the sine bar method and the SKF 9205 taper gauge method.

In this issue, you'll learn more about the SKF 9205 taper gauge, but let's run through some important reminders first.

1. Tapered bores

Most SKF spherical roller bearings and CARB toroidal roller bearings designed for tapered journals have a 1:12 bore taper (denoted by the suffix K). The exception is bearings from the 240, 241, C40 and C41 series that have 1:30 taper bores (suffix K30).

When you move a distance (L) up a 1:12 taper from a diameter (d) towards a larger one (d_1), $d_1 = d + (L/12)$. With a 1:30 taper, $d_1 = d + (L/30)$.

Calculations are simple once this is understood. For example, a 24172 ECCK30J/W33 has a nominal bore diameter of 360 mm at the narrow end of the taper and its width is 243 mm. The bore diameter at the wide end of the taper is 360 + (240/30) = 368,10 mm.

What about a 23184 CKJ/C4W33 with bore damage caused by ring rotation on the journal? It can be repaired at an SKF remanufacturing centre, but grinding is involved leading to a 0,1 mm increase in diameter along the taper. What influence does this have on the bearing position on the journal? Knowing that $d_1 = d + 0{,}1$, the question is what is L?

$d_1 = d + (L/12)$
$\Leftrightarrow d + 0{,}1 = d + (L/12)$
$\Leftrightarrow 0{,}1 = L/12$
$0{,}1 \times 12 = 1{,}2$ mm
So, the bearing will be 1,2 mm closer to the middle of the roll.

2. How to use the SKF 9205 taper gauge

See *issue 13 of SKF Pulp & Paper Practices*. If you haven't already read it, please do so before reading on. If you don't, the rest of this is issue will be hard to follow.

2.1 What does the SKF 9205 taper gauge look like?

The SKF 9205 taper gauge is a straightedge with two gauge pins. There are ten designs available, five for 1:30 tapers and five for 1:12 tapers (→ **figure 1**).

The designation for 1:12 taper straightedges is SKF 920512 and it's SKF 920530 for 1:30 tapers. The distance between the two gauging pins in millimetres, G, is indicated as a suffix in the designation (→ **figure 2**). So, for example, SKF 920512-80 is designed for 1:12 tapers and the distance between the two gauging pins is 80 mm. The straightedges are available with different G measurements i.e. 50 mm, 80 mm, 130 mm, 210 mm and 350 mm.

The straightedge is positioned at a distance, B_c, from the reference face using a distance piece. The distance piece is attached to the straightedge and can be custom made for a specific application (see the cover of this issue of *SKF Pulp & Paper Practices*) or a less accurate adjustable one can be used (→ **figure 3**).

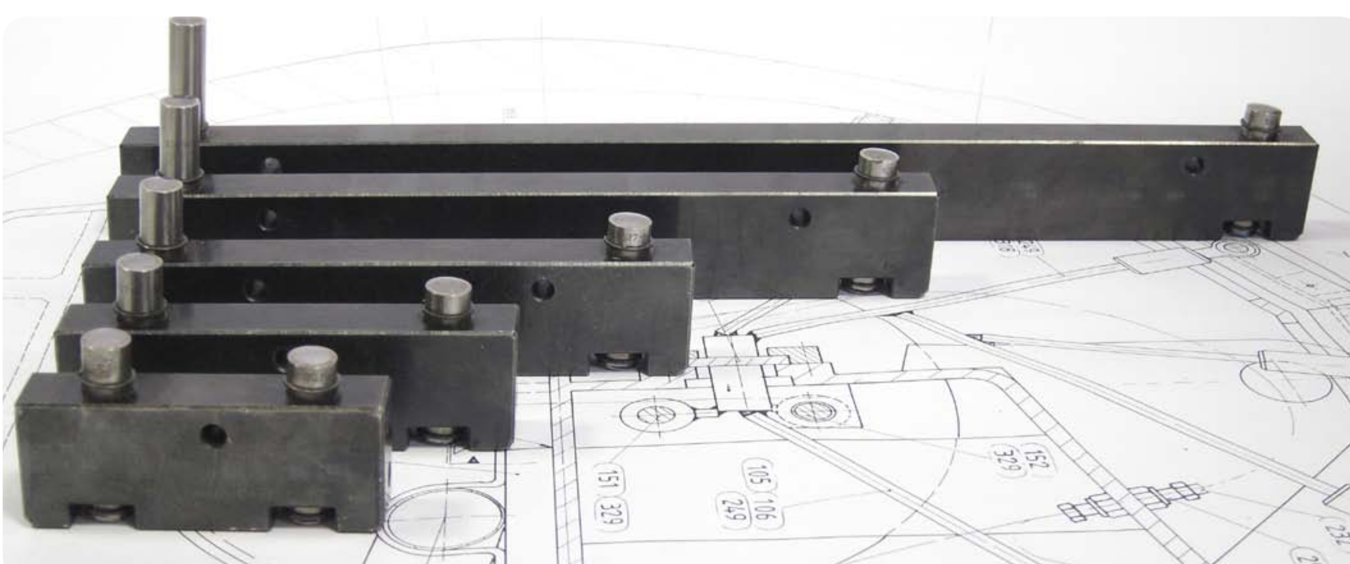


***Fig. 1** Five straightedges of various lengths for 1:12 tapers.*

The straightedge is held in place by one or two saddles and is secured using locking pins. A magnet is placed behind it to prevent movement during measuring. Straps are used to hold the taper gauge in position when necessary.

A complete SKF taper gauge set includes five straightedges, two saddles, two straps, two magnets and an adjustable distance piece (→ **figure 4**).

2.2 Calculations necessary to use the SKF 9205 taper gauge

In the following sections, I will provide worked examples for a SKF 241/600 ECAK30/C083W33 bearing in a plain press roll application (→ **figure 5**).

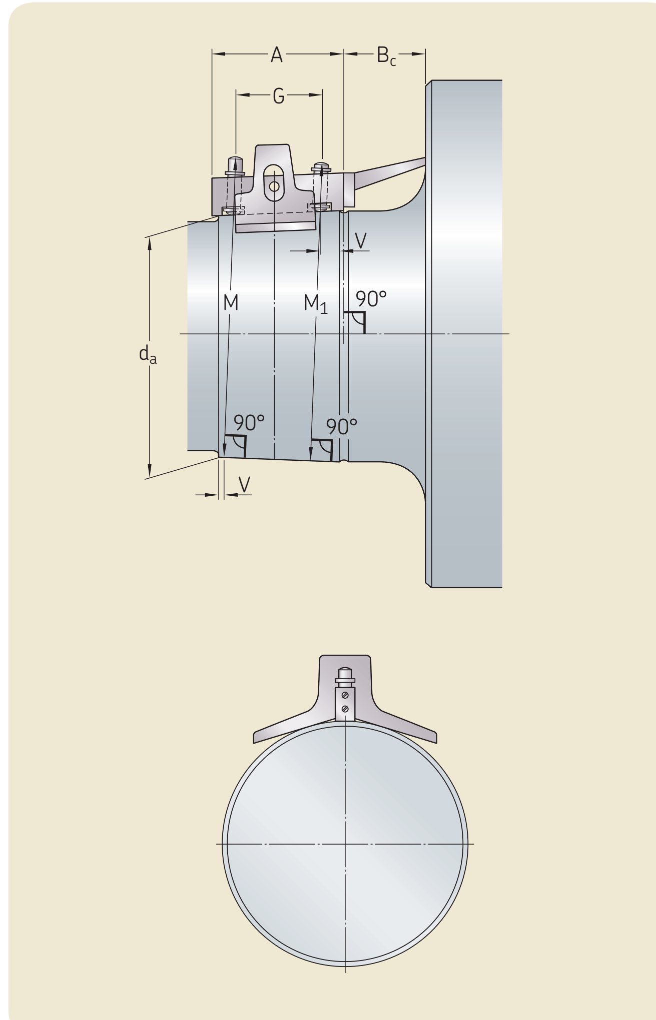


Fig. 2 The SKF 9205 taper gauge on a tapered journal.

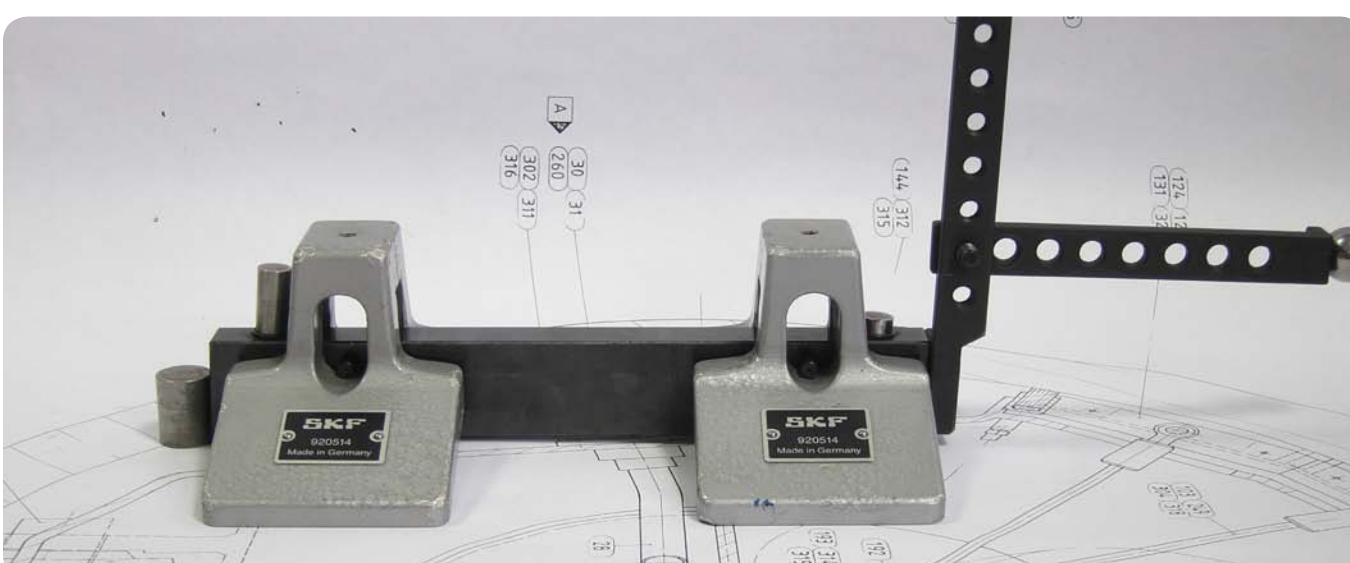


Fig. 3 An SKF 920512-210 taper gauge with two saddles (SKF 920514), a permanent magnet and an adjustable distance piece.

2.2.1 Nominal journal diameter

The dimension, Ba, is used as a basis when measuring a tapered journal with a SKF 9205 taper gauge. It's the distance from the centre of the bearing as finally mounted to the reference face of the journal (→ **figure 6**).

> **Note:**
> After mounting, the centre of our SKF 241/600 ECAK30/C083W33 bearing is 490 mm from the journal shoulder reference face and the taper width, B_e, is 370 mm.

Knowing B_a and the bearing dimensions, it is possible to calculate the nominal journal diameter, d_a, and its distance, B_d, from the reference face.

The nominal journal diameter, d_a, is bigger than the bearing bore diameter, d.

The bearing nominal bore, d, is the diameter of the inner ring bore taper in the radial plane passing by the ring face. In reality, between the ring face and the bore there is a chamfer and there's no contact between the journal and bearing. There is contact further up the bore after the chamfer. If B_f is equal to the chamfer radius, then contact occurs at a distance of B_f from the ring face (→ **figure 6**). The diameter of the taper increases by a value equal to B_f/K. Remember that K equals either 12 or 30 depending on the taper angle. The default value for B_f can be found in **table 1**. For SKF 241/600 ECAK30/C083W33, B_f = 10 mm.

Note that bearings are manufactured with tolerances for both the nominal bore diameter and the taper deviation (→ **figure 7**).

Fig. 4 Complete SKF 920512 taper gauge set.

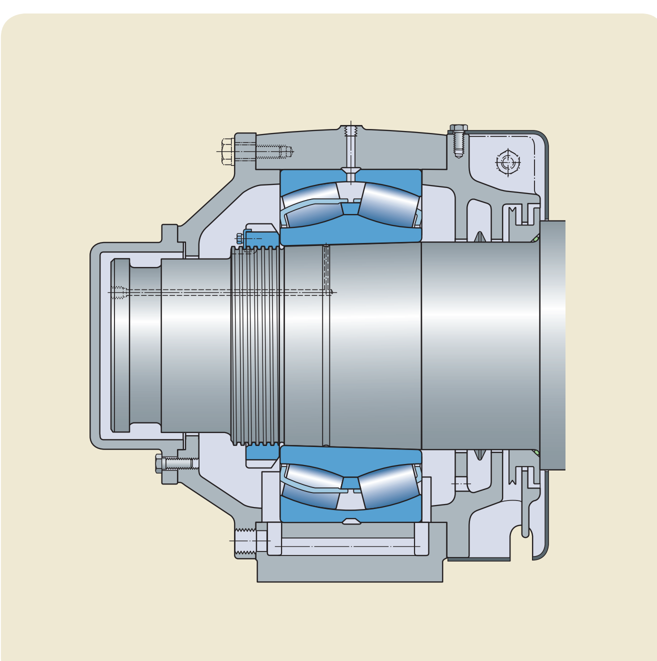


Fig. 5 Example of a plain press roll bearing arrangement from the SKF Rolling bearings in paper machines handbook.

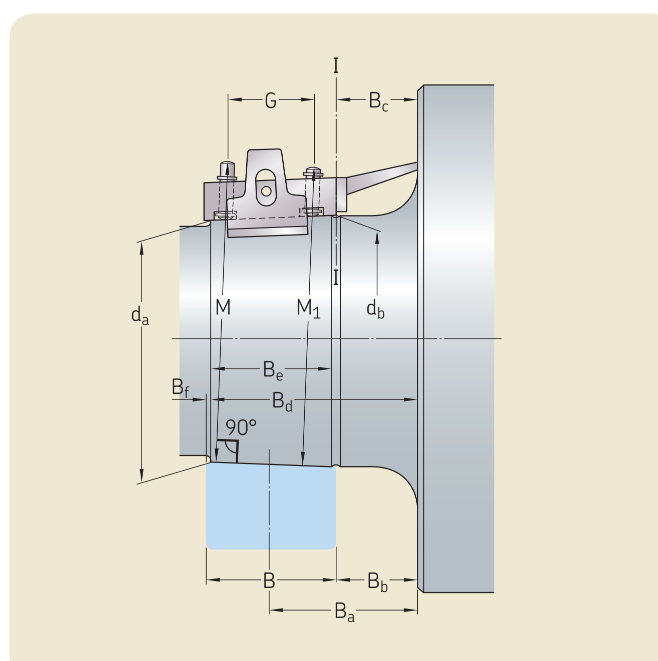


Fig. 6 The dimensions required for using the SKF 9205 taper gauge.

Note:
For SKF 241/600 ECAK30/C083W33, Δdmp, which is the deviation of the bore diameter from the nominal, is between 0,000 and +0,050 mm. This means that, in reality, the bearing narrowest bore diameter is between 600,000 and 600,050 mm.

If the taper bore angle is perfect, there would be the same deviation in all radial planes along the taper. If this is not the case, the bearing bore angle is manufactured within certain tolerances.

(Δd_1mp – Δdmp) is always positive. Δd_1mp is the deviation of the mean bore diameter at the theoretical large end of a tapered bore from the nominal. For the SKF 241/600 ECAK30/C083W33,

(Δd_1mp – Δdmp) is between 0,000 and +0,070 mm. Values can be found on **pages 145** and **146** of the *SKF rolling bearings catalogue* (SKF publication number 10 000).

To calculate the nominal journal diameter, d_a, the mean value of the bore tolerance of the bearing, T_m, and the taper deviation from the nominal are taken into account. T_m is added to d (→ **table 1** for the T_m values for normal precision SKF bearings).

Note:
For better understanding, let's calculate the T_m value for SKF 241/600 ECAK30/C083W33. The bearing nominal bore d is 600 mm and the real value after manufacturing is somewhere between 600,000 and 600,050 mm. The mean value is 600,025 mm.

If the taper angle is perfect and the mean value of 600,025 mm is taken, the diameter at the other side of the inner ring will be 600,025 + 375/30 (since the bearing width, B, is 375 mm and the taper is 1:30) i.e. 612,525 mm. However, the taper angle isn't perfect and the deviation is 0,000; +0,070 in this case. The mean deviation due to taper angle tolerance is then 0,070/2 = 0,035 mm. The mean diameter at the widest bore side is 612,525 + 0,035 = 612,560 mm.

The mean value at the middle of the bearing = (600,025 + 612,560)/2 = 606,2925 mm. The nominal diameter at the middle of the bearing = 600 + [(375)/2]/30 =606,250 mm. The mean deviation = T_m = 606,2925 – 606,250 =0,0425 (which we round to 0,042 or 0,043 mm).

Once understood, the calculation can be done more quickly since bearing width has no influence. The mean deviation at both the narrow end and the wide end of the taper is 0,025 mm. With the addition of the mean deviation due to the taper (0,035 mm), there is 0,060 mm deviation at the wide end. Calculating the mean deviation of the two gives you T_m i.e. (0,025 mm + 0,060 mm)/2 = 0,0425 mm.

Now you know how to calculate T_m for bearings other than the SKF normal precision class ones.

For bearings mounted with an interference fit, the taper journal at the bearing's final mounted position needs to be larger than the bearing bore. As a rule of thumb, there's a factor of 1,1 which is an average value for the relationship between the interference of the inner ring on the journal and the actual reduction in bearing radial clearance.

Be careful though as this factor is only valid for solid journals and journals with a bore diameter below half the nominal journal diameter. Or, to make things easier, simply take half the bearing nominal bore diameter.

If the journal bore is larger than half the bearing nominal bore, the factor should be increased. In such cases, I advise contacting the local SKF application engineering department.

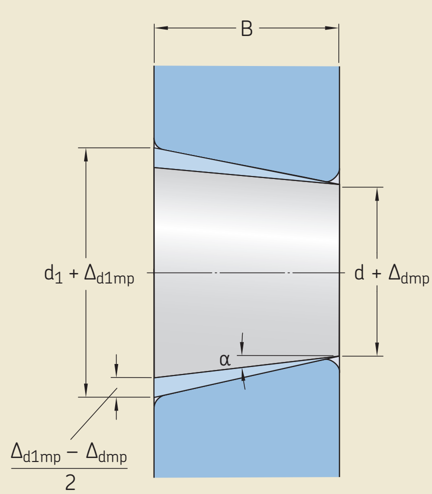


Fig. 7 Tolerances for 1:30 taper bores.

Nominal bore diameter of bearing d		T_m		B_f
Over	Include	1:12 taper	1:30 taper	
100	120	0,026	0,019	3
120	140	0,030	0,023	3
140	180	0,030	0,023	4
180	250	0,035	0,027	4
250	315	0,039	0,031	6
315	400	0,043	0,034	6
400	500	0,047	0,038	8
500	560	0,053	0,043	8
560	630	0,053	0,043	10
630	800	0,060	0,063	10
800	1 000	0,068	0,075	10
1 000	1 250	0,079	0,091	12
1 250	1 600	0,094	0,111	15
1 600	2 000	0,113	0,138	15

Table 1 Values for T_m and B_f for normal precision class SKF bearings only.

In general, SKF recommends a tight fit giving a clearance reduction of 0,0005 of the nominal bearing bore, d, for pulp and paper applications. Some pulp and paper applications, however, require tighter fits.

As such, an adjustment must be added to d in order to calculate d_a: 1,1 × 0,0005 × d = 0,00055 d.

Finally:
$d_a = d + (B_f/K) + T_m + 0{,}00055\ d$
$d_a = 1{,}00055\ d + B_f/K + T_m$

(Based on **figure 6**) $B_d = B_a + B/2 - B_f$

Note:
For SKF 241/600 ECAK30/C083W33:
$d_a = (1{,}00055 \times 600) + (10/30) + 0{,}042 = 600{,}7053$ mm
$B_d = 490 + 375/2 - 10 = 667{,}500$ mm

2.2.2 Selecting the right straightedge

For accurate measuring results, the distance, G, between the gauging pins should cover as much of the width of the taper, Be, as possible. However, G is limited by the space needed to accommodate the gauge pins and micrometer screw at each end of the taper (see the V distances shown in **figure 3**).

For 1:30 tapers, $G < B_e - (2V) - 0{,}02\ d_a$
For 1:12 tapers, $G < B_e - (2V) - 0{,}05\ d_a$

If d_a is equal to or smaller than 180 mm, then V should be at least 5 mm.

If d_a is greater than 180 mm, and up to equal to 400 mm, then V should be at least 7 mm.

If d_a is greater than 400 mm, then V should be at least 9 mm.

0,02 d_a and 0,05 d_a are approximations based on the diameter of the journal and the taper angle that should allow the micrometer to contact the taper and measure M at the narrow end of the taper bore.

Note:
For SKF 241/600 ECAK30/C083W33, d_a is greater than 400 mm so the minimum value for V is 9 mm.

$B_e = 370$ mm
$d_a = 600{,}7053$ mm
$G < 370 - (2 \times 9) - (0{,}02 \times 600{,}7053) = 339{,}986$ mm

As such, the straightedge SKF 920530-210 should be chosen.

2.2.3 Selecting the right distance piece length

The distance piece length must allow accurate measurements. The centres of the gauging pins are positioned 20 mm from the end face of the SKF straightedges. The value V must be added to the minimum length or subtracted from the maximum length when selecting the distance piece length. The position of the narrower end of the taper and the wider end must also be taken into account.

Minimum length:
$B_c\ min = B_d - B_e - 20 + V$

Maximum length:
For 1:30 tapers: $B_c\ max = B_d - G - 20 - V - 0{,}02\ d_a$
For 1:12 tapers: $B_c\ max = B_d - G - 20 - V - 0{,}05\ d_a$

Note:
For SKF 241/600 ECAK30/C083W33, $B_d = 667{,}500$ mm, $B_e = 370$ mm, V = 9 mm, G is 210 mm and $d_a = 600{,}7053$ mm. As such, B_c must be between 286,5 mm and 416,5 mm and we'd choose a 350 mm distance piece. Therefore, $B_c = 350$ mm.

2.2.4 Calculating the nominal value for M

Having selected a straightedge and a distance piece of suitable length, the diameter d_b in the plane I-I is calculated (→ **figure 6**). This plane coincides with the inner end face of the straightedge.

$d_b = d_a + (B_d - B_c)/k$

Note:
For SKF 241/600 ECAK30/C083W33, $B_d = 667{,}500$ mm, $B_c = 350$ mm, k = 30 and $d_a = 600{,}7053$ mm
$d_b = 600{,}7053 + (667{,}500 - 350)/30 = 611{,}2886$ mm

Using d_b, the nominal value for M is calculated using the relevant equation below.

For 1:30 tapers: $M = d_b - 0{,}000139\ d_b + 44{,}346$
For 1:12 tapers: $M = d_b - 0{,}000867\ d_b + 43{,}413$

Note:
For SKF 241/600 ECAK30/C083W33, $d_b = 611{,}2886$ mm, M then equals $611{,}2886 - (0{,}000139 \times 611{,}2886) + 44{,}346 = 655{,}5496$ mm

2.3 Tolerances for the tapered journal

When machining a journal, a certain tolerance must be allowed which applies to the dimensions M and M_1–M.

Over the years, tolerances have changed. Some changes are small like the tolerance for M which was j9 and is now js9Ⓔ. Others, like the changes on the taper angle deviation, are much more important. Some old journals on machines that are still in operation today are out of tolerance by today's standards.

Note:
For SKF 241/600 ECAK30/C083W33 d= 600 mm
js9Ⓔ for 600 mm is ± 0,087 mm
So M = 655,5496 mm (–0,087 ; +0,087)

Different approaches were used when the tolerances for tapered journal seatings were being established. The European system was based on the permissible angle deviation for the journal taper being on the plus side, like we do for bearings, and the tolerance value was related to the nominal diameter of the journal. In contrast, the US approach was to have a permissible deviation on the minus side and to use the nominal width of the bearing. These different approaches have, understandably, led to practical difficulties.

Since 1986, the permissible angle deviation for machining the taper is a plus/minus tolerance in accordance with ±IT7/2. The value is determined in relation to the bearing width.

Note:
For SKF 241/600 ECAK30/C083W33, B =375 and IT7 for 375 mm is 0,057 mm.
±IT7/2 = (–0,0285; +0,0285)

As the gauge pins are separated by a distance, G, which is not equal to the bearing width, B, the tolerance on M_1–M will be equal to (G/B) × (±IT7/2)

Note:
For SKF 241/600 ECAK30/C083W33, G = 210, B = 375 and ±IT7/2 = ±0,0285 mm.
So M_1–M limits are (210/375) × (±0,0285) = ±0,016 mm

As increased reduced run-out tolerances are needed for faster-running modern machines, the radial deviations from circularity have changed. In the past, IT6/2 was used with IT5/2 recommended for cases requiring reduced run-out tolerances. Today, IT5/2 is used and IT4/2 is recommended when higher accuracy is needed. IT4/2 should be used when bearings with reduced run-out tolerances – like SKF's C08, VQ424 and VA460 bearings – are required. The value is determined in relation to the nominal bearing bore diameter and applies to both M and M_1 maximum deviation values as measure at several locations around the journal.

Note:
SKF 241/600 ECAK30/C083W33 has a C08 suffix so the journal should have a circularity following IT4/2.

Be careful though as circularity deviation definition is based on the radius, not the diameter. So, the value must be doubled when gauging with a micrometer, thus IT4 not IT4/2. IT4 for 600 mm is 0,022 mm.

Most documents didn't show IT4 for nominal dimensions above 500 mm. You can find it in the norm ISO 286-1:2010.

So, after measuring M and M_1 in several positions around the journal, maximum measured M minus minimum measured M value should not be above 0,022 mm. The same applies for M_1.

2.4 Straightness

Straightness tolerance is IT5/2 and is based on the bearing diameter. As straightness deviation applies to the generatrices of the taper, permissible tolerance is doubled if measurement is done with a micrometer over the diameter.

Note:
For SKF 241/600 ECAK30/C083W33, IT5/2 is 0,016 mm. When measuring with a micrometer over the diameter, the tolerance is 0,032 mm.

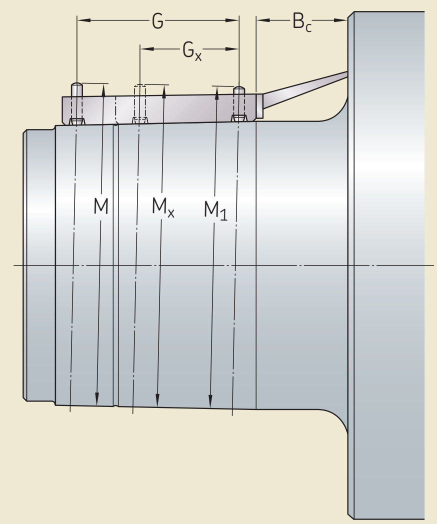


Fig. 8 Checking straightness with the SKF 9205 taper gauge.

The straightness of a tapered seating is quite difficult to measure, but some methods were explained in the previous issue of *SKF Pulp and Paper Practices*.

The SKF 9205 gauge can be used to estimate straightness. The gauge pin closest to the distance piece always has the same height and will always be in the same position regardless of the length of the straightedge. This means that M values are the same if the same distance piece is used.

Taper angle deviation as expressed by M_1–M must always be taken into account. If M_1–M_x have the same angle deviation, there's perfect straightness (→ **figure 8**). Given that G_x is smaller, M_1–M and M_1–M_x will have the same angle deviation if M_1–M_x = (G_x/G).(M_1–M).

The straightness of the tapered seating is within tolerance if, at the measured points,

$(G_x/G).(M_1\text{-}M) - IT5/2 < M_1–M_x < (G_x/G).(M_1–M) + IT5/2$

Note that this is valid for one axial plane so M, M_1 and M_x must be in the same axial plane.

Note:
For SKF 241/600 ECAK30/C083W33, the calculated M value will remain equal to 655,5496 mm with the following SKF straightedges: 920530-50, 920530-80, 920530-130, 920530-210.
Let's suppose that M = 655,550 mm and that M_1 = 655,560 mm with the SKF 920530-210 straightedge. The next measurement is undertaken with the SKF 920530-130 and the same distance piece.

G = 210
G_x = 130
G_x/G = 0,6190
M_1–M = 0,010
IT5/2 = 0,016

$(0,619 \times 0,010) - 0,016 < M_1 - M_x < (0,619 \times 0,010) + 0,016$

$-0,0098 < M_1 - M_x < 0,0222$

So, the straightness based on three points is within tolerance if, after rounding the values,

$655,538 < M_x < 655,570$.

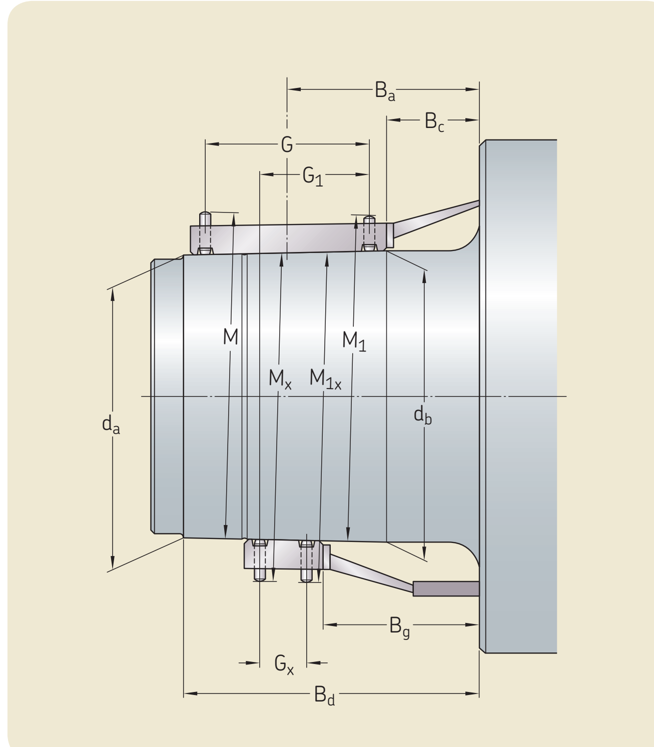


Fig. 9 Checking straightness with the SKF 9205 taper gauge and two distance pieces.

This method should be used in conjunction with the Prussian blue method which will indicate the contact percentage. If that's below the recommended level, select a straightedge with a gauging pin position suitable for the area that needs to be measured.

If no suitable straightedge is available, it's possible to take measurements using another distance piece and a smaller straightedge (→ **figure 9**). While the gauges are shown spaced apart by 180° for ease of understanding, in reality it's important that comparative measurements of M, M_1, M_x and M_{1x} are taken at the same position on the journal.

In **figure 9**, M_x is the diameter where there is a supposed straightness deviation. A new distance piece is added so that the smaller straightedge is at a distance, B_g, from the reference face. The distance between the M_1 and M_x gauging pins is now G_1.
$G_1 = G_x + B_g - B_c$.

As the smaller straightedge is now further away from the reference face, the M_x value will be smaller than M and M_1. The difference in diameter which is $(B_g - B_c)/k$, must be added to compare M_1 and M_x.

$M_1 - M_x = (G_1/G).(M_1 - M) + (B_g - B_c)/k$

The straightness is within tolerance if:

$(G_1/G).(M_1 - M) + (B_g - B_c)/k - IT5/2 < M_1 - M_x < (G_1/G).(M_1 - M) + (B_g - B_c)/k + IT5/2$

2.5 Determining the width of the spacer ring

It's possible to determine the width of a spacer ring against which a bearing will be driven up for a correct tight fit for bearings with a 1:30 taper.

Note that some bearings with a 1:12 taper can also be mounted in this way. Such bearings must be manufactured with the reference face at the large end of the taper and to close bore tolerances applying to a taper of 1:30. These bearings have special designations and prices.

Note:
SKF 241/600 ECAK30/C083W33 has a taper of 1:30 and can be mounted against a spacer ring whose width is determined in advance with the SKF 9205 taper gauge.

The nominal width of the ring is (→ **figure 6**):

$B_b = B_d + B_f - B$

where all dimensions are nominal.

The actual width of the ring for the same journal is obtained using:

$B_{be} = B_b + k.\Delta M$

Where ΔM is the measured positive or negative deviation from the nominal M deviation.

Note:
For SKF 241/600 ECAK30/C083W33, nominal M = 655,5496 mm.

Measured M value is 655,550 mm at the 0° (the top) position.
Measured M value is 655,570 mm at the 45° position.
Measured M value is 655,562 mm at the 90° position.
Measured M value is 655,559 mm at the 135° position.
The average measured value is then 655,5603 mm

ΔM = 655,5603 – 655,5496 = 0,0107 mm
B_d = 667,500 mm
B_f = 10 mm
B = 375 mm
B_{be} = 667,5 + 10 – 375 + (30 × 0,0107) = 302,819 mm

For the rings to have the necessary adjustment allowance, they must be manufactured wider:

$B_h = B_b + k.h$

Where h is the upper limit for M in accordance of js9Ⓔ determined in accordance to the bearing bore diameter.

Note:
For SKF 241/600 ECAK30/C083W33, js9Ⓔ for 600 mm is ±0.087 mm.

B_h = 667,5 + 10 – 375 + (30 × 0,087) = 305,110 mm.

Several 305,110 mm width spacer rings should be made and then machined or ground to a specific width after having measured the M values around the journal and calculated the average M.

Note that each adjusted spacer ring is for one unique journal and should not be used with another one.

3. Measuring uncertainty

Remember that even though the tool is called a micrometer, it isn't able to measure with a precision of one micron. Other things can affect the accuracy of a measurement too e.g. the influence of the tool user's body heat. A leading tool manufacturer gives an example of this based on the use of a 300 mm micrometer for 15 minutes in a room that's at a temperature of 20 °C which adds 12 µm.

The direction of measurement is also important. Even if a journal has perfect circularity, the micrometer will measure a deviation between the vertical and horizontal positions as it will deform under its own weight.

To minimise uncertainty and error it's important to always check a micrometer before and after measurement using a standard at ambient temperature.

In the absence of other information, a simple rule of thumb is that measuring uncertainty when using a micrometer is estimated to be ±0,1 IT9/2.

Note:
For SKF 241/600 ECAK30/C083W33, the uncertainty when measuring M would be ±0,0087 mm.

For better accuracy, especially for journals supported by C08, VQ424 and VA460 bearings that have reduced run-out tolerances, a dial indicator should be used. Then, estimated uncertainty falls to ±0,1 IT7/2

Note:
Our SKF 241/600 ECAK30/C083W33 is a C08 bearing, so a dial indicator should be used. The uncertainty is then estimated to be ±0,0035 mm.

To conclude, the SKF 9205 taper gauge is a good tool that will never run out of battery power and which can withstand submersion in oil. At first, it can seem like a complicated tool to use due to all the equations involved. These can, of course, be run using a spreadsheet so that you simply need to enter input data.

I have tried to make my explanation of the tool's use as simple as possible by giving worked examples throughout this issue of SKF Pulp & Paper Practices. I will also add that once the SKF 9205 principle is understood, it becomes obvious and you will never forget it. It's just the first few times using it that are difficult.

Regards,
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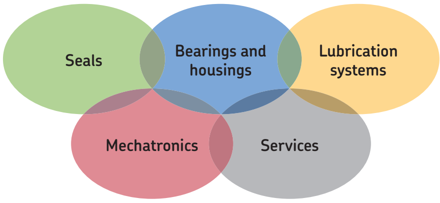

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