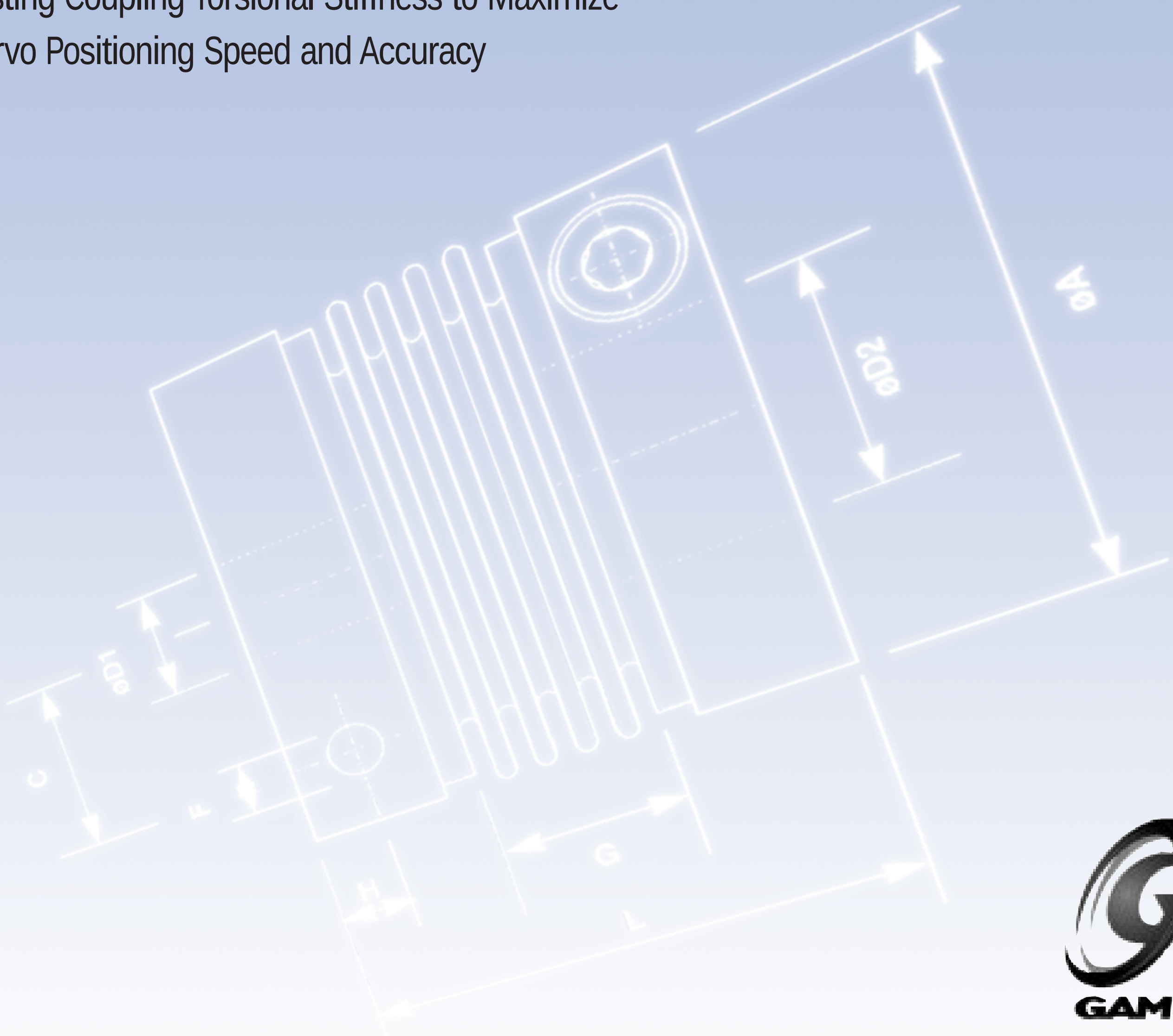
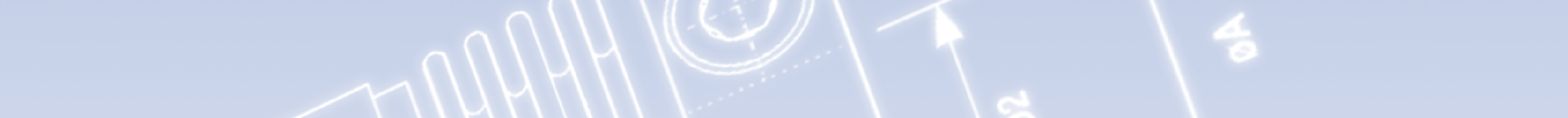
Gam Dynamics

Volume 1.1 **Power and Motion Technology Reports From Gam**

Testing Coupling Torsional Stiffness to Maximize Servo Positioning Speed and Accuracy





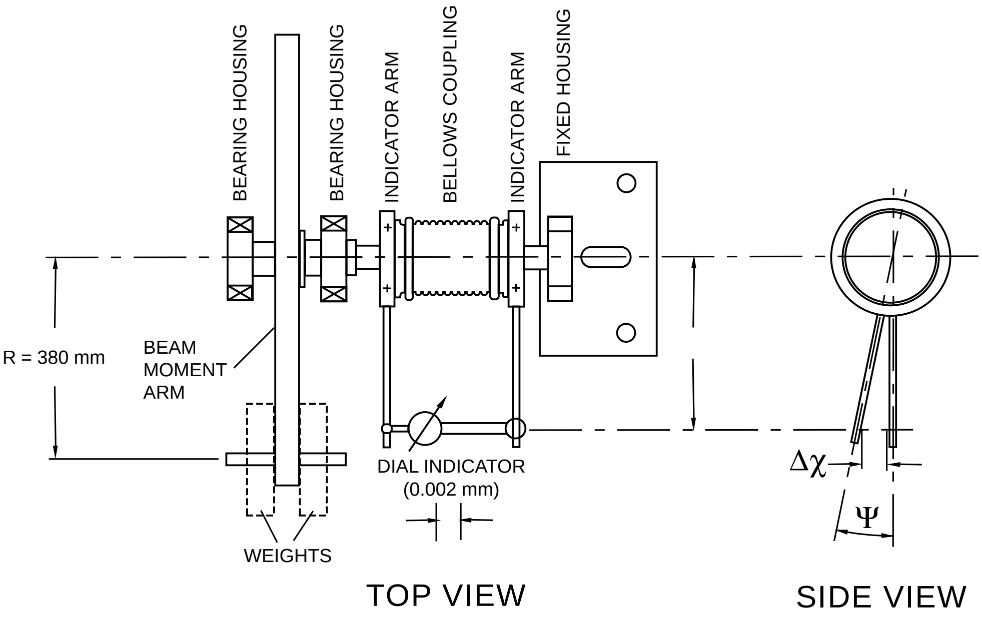
Can there be a significant difference between a coupling's published and measured torsional stiffness?

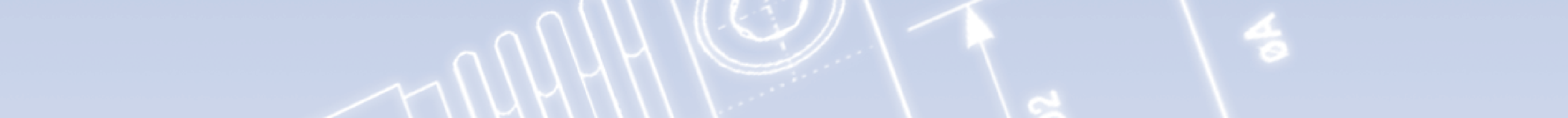
An Independent Study Using a Consistent Test Method Reveals the Answer. Read On...

With today's increasing reliance on faster servo systems for motion control, even small variations in the stiffness of a powertrain can significantly affect positioning accuracy or constrain cycling speeds. While many factors may be involved, a very important one is the stiffness of the couplings used to connect moving machine components.

Metal bellows couplings like the Gam/Jakob units we produce are very frequently used in servo and motion control systems. The metal bellows design offers a very high level of torsional stiffness that designers recognize as among the best available. At the same time, metal bellows couplings are capable of accommodating significant misalignments between powertrain components. In fact, no other coupling style balances these two design requirements so well. So it's no surprise they're so frequently specified to compensate for assembly misalignments, bearing wear, vibration and thermally induced dimensional changes.

Figure 1: **Test Fixture for Measuring Torsional Stiffness of Bellows Couplings**





Higher Cycling Speeds and Accuracy Requirements Increase Torsional Stiffness Demands

Today's motion control systems are operating at unprecedented speeds, with extremely rapid start/stop cycling and directional changes. Consequently, designers are running up against the practical limitations of the torsional stiffness of bellows couplings — unusual 10 years ago but increasingly common today.

Having arrived at the far end of the stiffness spectrum, it's never been more important for designers to know how much torsional stiffness they're really working with and how far it can be pushed. As we at Gam have worked in this area, we've come to recognize that designers often don't have access to coupling torsional stiffness data that's consistent from one manufacturer to the next. Different manufacturers' published stiffness ratings can vary widely depending on the test methods they use, and may even be overstated.

Conversely, the ability to make direct comparisons between competing products would allow the designer to select the optimum coupling for a given application. This report is devoted to describing a stiffness testing method and the sometimes surprising results it yielded.

A Test Fixture to Measure Torsional Stiffness

The test fixture shown in Figure 1 was designed to accommodate many sizes of couplings. An independent testing firm was used to ensure objectivity and credibility.

To conduct tests, one end of a bellows coupling is attached to the fixed housing indicated in the drawing. The opposite end of the coupling is attached to a freely moving beam moment arm capable of being loaded with various weights. A dial indicator attached to the fixed and freely moving ends is used to measure the coupling's torsional deflection under varying loads. The fixture measures the coupling's overall stiffness, including the end hubs and the bellows.

Four coupling models from each of three manufacturers were tested; two sets of measurements were taken for each coupling. Each set of measurements involved tests with between five and seven weights of different masses applied to the beam moment arm; masses ranged between 4.54 kg and 45.17 kg, depending on the published ratings of the couplings. The couplings were tested to rated torque values except where noted. Table 1 provides information on the manufacturers, model numbers and rated torque values for the coupling tests covered in this report.

Table 1: Couplings Tested for Torsional Stiffness

Test 1

Coupling	Manufacturer	Mfr. Part Number	Rated Torque
A	Gerwah	AKN 60	60 Nm
B	Gam/Jakob	KP 60	60 Nm
C	R&W	BK2-60/83	60 Nm

Test 2

Coupling	Manufacturer	Mfr. Part Number	Rated Torque
A	Gerwah	AKD 150	150 Nm
B	Gam/Jakob	KM 170	170 Nm
C	R&W	BK2-150/107	150 Nm

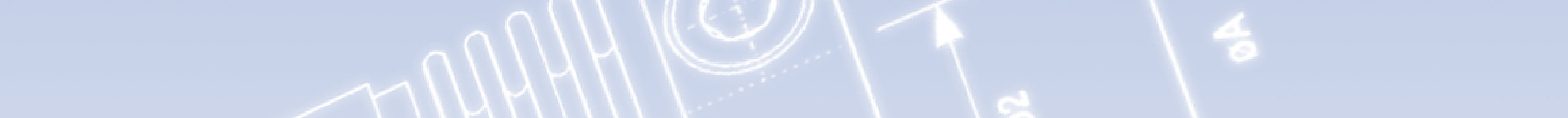
Test 3

Coupling	Manufacturer	Mfr. Part Number	Rated Torque
A	Gerwah	AKN 150	150 Nm
B	Gam/Jakob	KP 170	170 Nm
C	R&W	BK2-150/95	150 Nm

Test 4*

Coupling	Manufacturer	Mfr. Part Number	Rated Torque
A	Gerwah	AK 500	500 Nm
B	Gam/Jakob	KSD 550	550 Nm
C	R&W	BK3-500/110	500 Nm

*Couplings for Test 4 were tested to 170 Nm.



Calculating Torsional Stiffness From the Tests

Torsional stiffness is a measurement of torque per angular displacement, and may be expressed as follows:

Ct = Torsional Stiffness (Nm/rad)

$Ct = M/\psi$

Where: M = Torque (Nm) and ψ = Angular Displacement (rad)

By applying a known mass at a known moment arm, torque may be determined as follows:

m = mass (kg)

g = Gravitational Acceleration (9.81 m/s^2)

R = Moment Arm (m) = 0.38 m

M = Torque (Nm) = mgR

The angular displacement may be determined from the dial indicator reading as follows:

Δx = Indicator reading (mm)

τ = Indicator moment arm (mm)

$\tan(\psi) = (\Delta x/\tau)$ (see Figure 1)

$\psi = \arctan(\Delta x/\tau)$ (deg)

Torsional stiffness is computed as follows:

$Ct = M/\psi$ (Nm/deg)

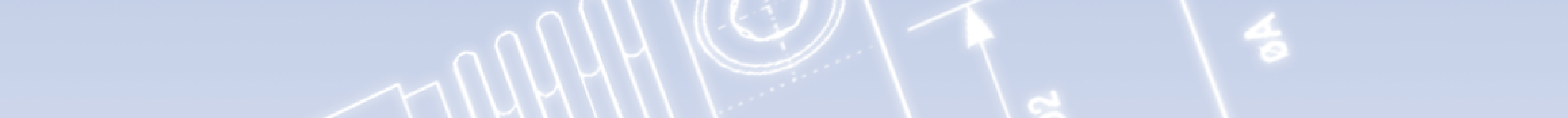
$Ct = M*180/\pi*\psi$ (Nm/rad)

The measured readings of the dial indicator, mass and moment arm were entered into a spreadsheet. The equations above were also entered into the spreadsheet to compute torsional stiffness values.

Table 2: Torsional Stiffness Testing Results for Gam/Jakob KP 60 Bellows Coupling

Test 1B.1: Gam/Jakob KP 60

Trial	Indicator Reading Δx (mm)	Test Mass m (kg)	Indicator Moment Arm τ (mm)	Torque M (Nm)	Measured Torsional Stiffness Ct x 10^3 (Nm/rad)	Published Torsional Stiffness Ct Catalog (Nm/rad)	Measured Torsional Stiffness as a Percentage of Published Stiffness
1	0.120	4.54	307.3	16.9	43.3	46	94.2
2	0.181	6.81	307.3	25.4	43.1	46	93.7
3	0.243	9.08	307.3	33.8	42.8	46	93.1
4	0.307	11.35	307.3	42.3	42.4	46	92.1
5	0.433	15.89	307.3	59.2	42.0	46	91.4
				AVG	42.7	46	92.9



Comparing Measured and Published Torsional Stiffness Ratings

An example of the values calculated from the measurement tests is provided in Table 2, displaying results for one test set on a Gam/Jakob KP 60 bellows coupling. At the bottom of the table, note that an average value is shown for measured torsional stiffness, based on testing conducted with the different masses indicated in the "Test Mass" column. There is also an average value provided for the ratio of measured to published torsional stiffness for the coupling.

While there isn't space in this report to provide detailed test results for all 12 couplings tested, a full data set is available upon request. However, Table 3 highlights the most critical data set in this report. It shows the percentage of each coupling's *published* torsional stiffness rating that was *actually measured* in these tests. Each reported percentage is a composite number obtained from between 10 and 14 individual torsion tests on a coupling.

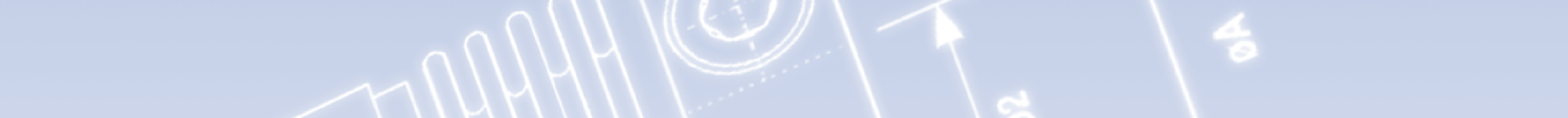
Of course, we'd like to stress that these results are based only on the test fixture and methodology we've described here. Results may vary as a result of fixture design and how the operator set up and performed the actual test runs.

What these numbers really tell us is that there can be some very significant differences between published and measured torsional stiffness values when a consistent test method is used for comparison. For the designer, that should serve as a caution when engineering a motion device whose ultimate performance relies heavily on overall stiffness.

The watchword, of course, is "test for yourself." If you establish a set of evaluation protocols that faithfully model the performance needs of your designs, then you can be confident you're getting the overall stiffness and system performance you intended. That's important when you're pushing all of your components and the design itself to the limits.

Table 3: Averaged Torsional Stiffness Testing Results for 12 Bellows Couplings

Test No.	Manufacturer	Mfr. Part Number	Average Measured Torsional Stiffness as a Percentage of Published Stiffness
1A.1, 1A.2	Gerwah	AKN 60	58.6
1B.1, 1B.2	Gam/Jakob	KP 60	92.2
1C.1, 1C.2	R & W	BK2-60/83	49.8
2A.1, 2A.2	Gerwah	AKD 150	65.1
2B.1, 2B.2	Gam/Jakob	KM 170	89.8
2C.1, 2C.2	R & W	BK2-150/107	48.9
3A.1, 3A.2	Gerwah	AKN 150	69.1
3B.1, 3B.2	Gam/Jakob	KP 170	90.1
3C.1, 3C.2	R & W	BK2-150/95	44.2
4A.1, 4A.2	Gerwah	AK 500	81.7
4B.1, 4B.2	Gam/Jakob	KSD 550	90.5
4C.1, 4C.2	R & W	BK3-500/110	35.1



Greater Stiffness Translates Into Faster Cycling in a Real-World Motion Control Example

What might these results mean in a real-world motion control setting? We see one example from one of our customers using Gam/Jakob bellows couplings in a motion control application in a printed circuit board drilling machine.

The machine uses bellows couplings to connect servomotors and lead screws used to position a 30 x 36-inch table in X and Y axes. Moving masses are in the range of 700 to 1000 pounds. Previous coupling designs had worked well, with no positioning accuracy problems. But design goals for upgrading the machine placed a premium on powertrain stiffness.

The customer tested many different couplings, and the results pointed to the superior stiffness of Gam/Jakob bellows couplings. In combination with a number of other design changes to increase overall system stiffness, the Gam/Jakob couplings helped the customer achieve a settling time frequency response as much as 50% better than previous models. And that improvement in positioning time lead to an 8 to 12% improvement in machine throughput.

For a copy of the full data set supporting this study and the composite results shown in Table 3, call us today at:

1.888.GAM.7117

We'll also be glad to provide you with additional copies of this issue of *Gam Dynamics*.