Experimental Determination of Kinematic Coupling Repeatability in Industrial and Laboratory Conditions

Patrick J. Willoughby, A. John Hart, Alexander H. Slocum
Massachusetts Institute of Technology, Cambridge, MA

While kinematic couplings are frequently used to create repeatable interfaces in ideal environments, their use in typical industrial interfaces is less frequent, as previous studies have described couplings mostly under modest loads and controlled environmental conditions. On the other hand, the performance of heavily loaded industrial equipment, such as robots used in automotive production, could benefit from highly repeatable interfaces for assembly and replacement of robot modules. A series of tests was conducted to assess the repeatability of large kinematic couplings on the ABB 6400R industrial robot, shown in Figure 1. Two of the more frequently replaced interfaces, the robot base to factory floor interface and the robot wrist interface, were used as test locations. While the base interface represents a high load, large size coupling, the wrist interface requires a smaller coupling subjected to a moderate load.

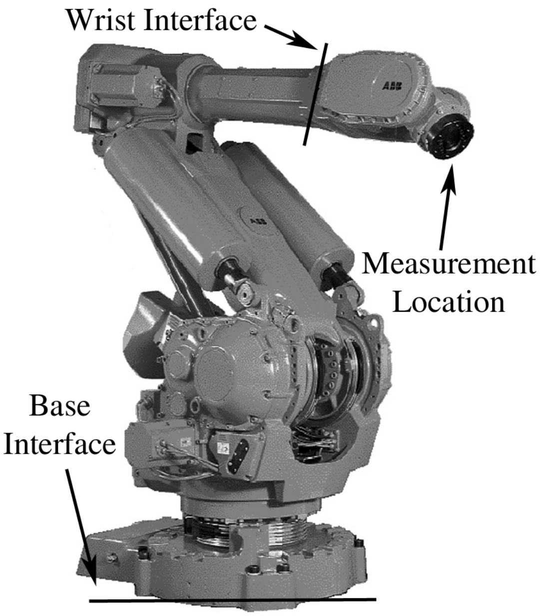

Figure 1 - ABB IRB 6400R Industrial Robot

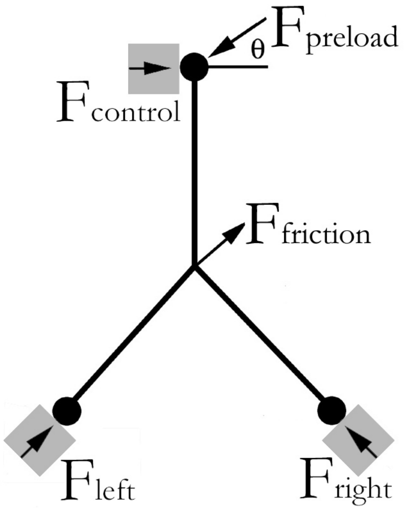

Figure 2 – Force Schematic for Three Pin Coupling

For both interfaces, replacements for the existing pin joint interfaces were designed using two forms of kinematic couplings – the three-pin coupling and the canoe-ball coupling. The three-pin coupling replaces the non-deterministic pin constraints with three line constraints for the in-plane degrees of freedom and a large planar constraint for the remaining degrees of freedom. Figure 2 shows a force schematic for the three pin coupling with the three pins shown in black and the mating surfaces in light grey. The canoe-ball couplings employ large radius spherical surfaces ground onto compact elements with matching groove elements to constrain the interfaces using six contact patches. Figure 3(a) shows a single canoe ball element with its mating groove element. To maximize stability, each coupling element is placed in the configuration shown in Figure 3(b) where the centerline of each groove bisect the coupling triangle and intersect at the coupling centroid.

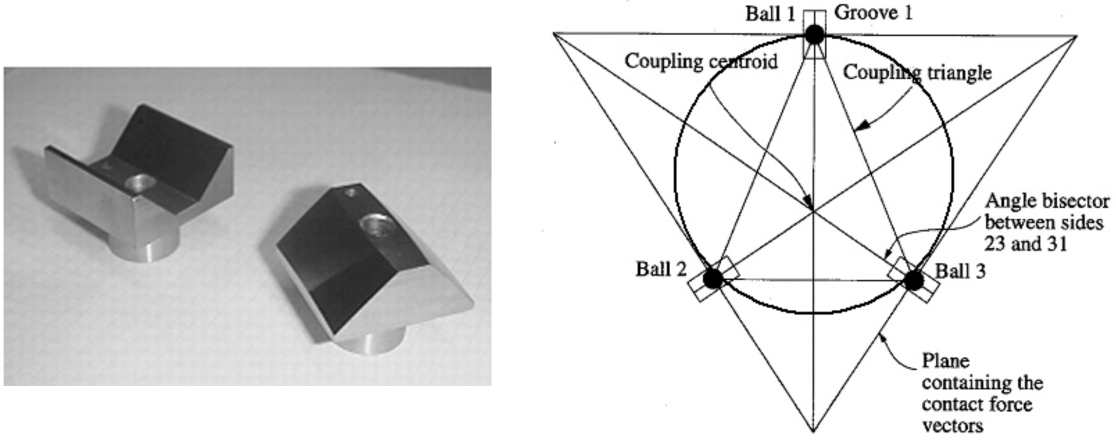

Figure 3 – (a) Canoe Ball and Groove Elements and (b) Standard Kinematic Coupling Circle

During industrial testing, measurements were taken for an embodiment of each coupling type on the base and wrist interfaces. For both interfaces, separate coupling plates containing the contacting elements were attached to the existing interfaces. The Leica LTD500 laser-tracking measurement system was used to measure the location of a retroreflector mounted on the robot's tool flange. The LTD500 has an accuracy of 0.01 mm per meter between the retroreflector and the motorized laser-tracking device. Each measurement set included a replacement using a basic installation method and one using a refined procedure consisting of the following steps:

1. Remove preload bolts and separate coupling interfaces using an overhead crane for support.
2. Inspect and carefully clean the contacting surfaces with methanol. Surfaces are not lubricated during the experiments.
3. Clean and grease all bolts.
4. Engage coupling interfaces with special attention to alignment of elements using an overhead crane for support.
5. Replace preload bolts and any additional bolts. Tighten bolts to design specification in a stepped fashion following a consistent pattern.

Additional low load, laboratory measurements were taken for the wrist couplings under gravity loading as a baseline comparison to previous studies. Similar deviations in installation procedure were analyzed for the laboratory measurements.

The primary conclusion from coupling performance measurements in both industrial and laboratory settings is that proper mounting of a kinematic coupling is equally important as, if not more important than, the presence of the kinematic interface. Careful attention to mounting conditions is required if kinematic couplings are to provide high repeatability for high-load bearing industrial interfaces. A factor of two to three improvement in repeatability is possible simply by switching from a basic mounting procedure to the refined installation procedure. Without properly applied, sufficient preload, frictional effects determine the interface position and prevent optimal repeatability, although Schouten has noted that flexures can be used to mitigate this effect. Laboratory measurements provided best case canoe-ball coupling repeatability on the order of 0.1μm and three pin coupling repeatability of 1μm. In industrial trials, the canoe-ball coupling was able to improve repeatability of the base interface by 93% and the wrist interface by 59%. The three-pin coupling was able to improve the base interface repeatability by 93%. Because of damage to the alignment features, the three-pin coupling on the wrist interface must undergo further industrial measurements to properly characterize repeatability. Repeatability data for industrial measurements are summarized in Figure 4 and Figure 5, while numerical data is shown in Table 1. The trends in the measurements indicate that the three-pin coupling is a lower cost, less repeatable alternative to the higher cost, more repeatable canoe ball couplings; however, as the physical size and scale of loading increase, this trend becomes less significant. While measurements for the laboratory experiments were taken at the center of stiffness, measurements for the industrial couplings were taken at a fixed distance from the coupling center. A simple approximation for the repeatability of the industrial couplings at the center of stiffness of each coupling indicates that the theoretical repeatability could be an order of magnitude less than the measured results. In general, both the three-pin and canoe-ball couplings measured in this study result in an order of magnitude improvement in coupling repeatability over the current interface designs for the IRB6400.

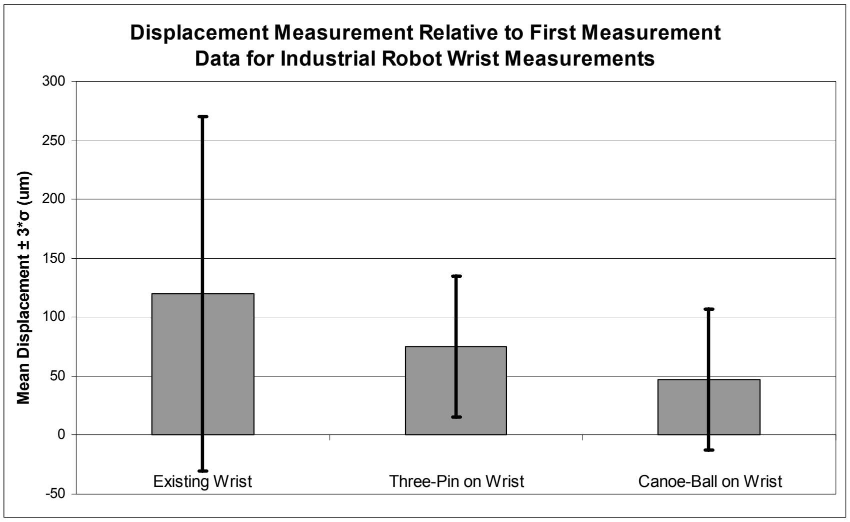

Figure 4 - Summary Plot of Industrial Data for Robot Wrist

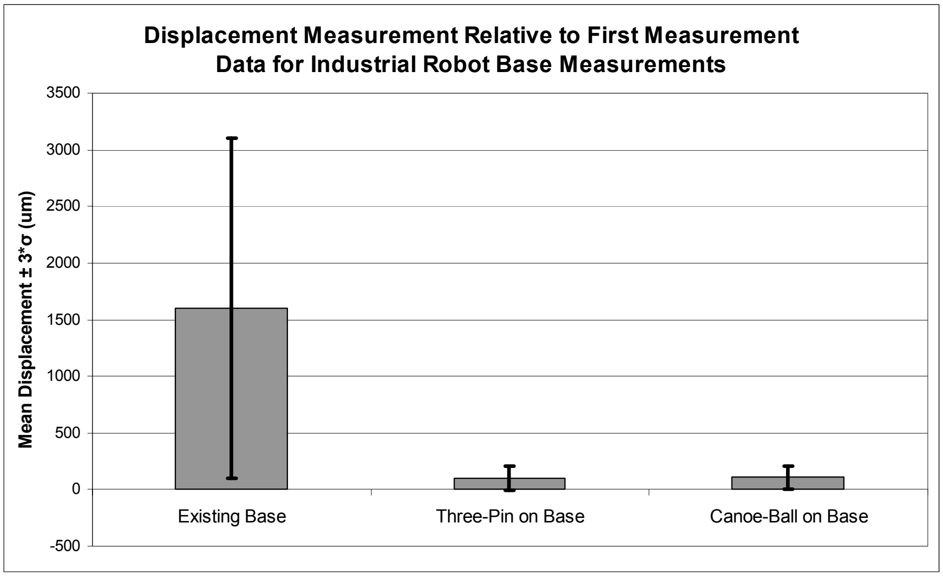

Figure 5 - Summary Plot of Industrial Data for Robot Base

Table 1: Best Case Results Summary

Experiment	Average Location Shift	Standard Deviation
Laboratory Canoe Balls - Unloaded	-0.04 µm	0.14 µm
Laboratory Canoe Balls – Design Preload	-0.69 µm	0.41 µm
Laboratory Three-pin – Design Preload	-0.09 µm	1.01 µm
Industrial Robot Wrist – Canoe Balls	50 µm	25 µm
Industrial Robot Wrist – Three-pin	80 µm	30 µm
Industrial Robot Base – Canoe Balls	110 µm	35 µm
Industrial Robot Base – Three-pin	100 µm	35 µm

Key words: kinematic couplings, robotics, repeatability, precision fixturing, three-pin, canoe-ball

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