# Quasi-Kinematic Couplings: A Low-Cost Method For Precision Coupling of Product Components and The Like In Manufacturing Processes

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## MOTIVATION

Traditionally, precision assemblies in high volume manufacturing have used pin-hole joints; however the evolution of more stringent design requirements has pushed the performance of this method to its practical performance limit of approximately five microns repeatability. Next generation designs (i.e. automotive engines and pump assemblies) require low-cost couplings which permit sealing between interfaces and deliver better than five micron repeatability. This presentation will introduce a fundamentally new type of kinematic coupling, the quasi-kinematic coupling, which costs less than most precision pinned joints, delivers sub-micron repeatability, and allows contact/sealing between mated components.

## GEOMETRY

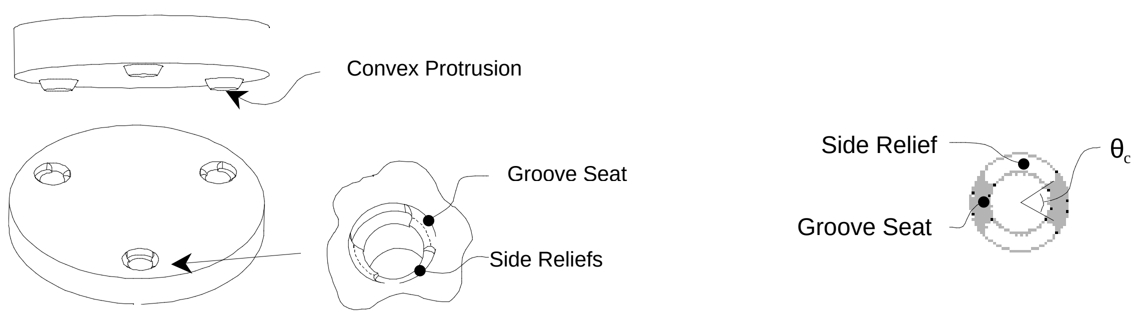



**Figure 1 QKC With Detail of Conical Groove and Contact Angle $\theta_c$**

In general, Quasi-Kinematic Couplings (QKCs) are well-suited for high volume precision assembly, particularly where integral locating features and/or sealing contact are required. Quasi-kinematic couplings are similar to traditional Kinematic Couplings as they consist of three convex protrusions which mate with three corresponding grooves. However, QKC grooves and convex surfaces are formed as surfaces of revolutions (i.e. for instance a conical hole). Mating the kinematic elements results in six arced lines of contact (two at each groove-protrusion joint) not six points as in a kinematic coupling. The result is a weakly over-constrained coupling whose behavior approaches that of a kinematic coupling as the groove seat contact angle ($\theta c$) decreases, thus the name quasi-kinematic.

## FUNCTION

Due to friction and surface irregularities (surface finish affects (Slocum, 1992)), when the coupling is first mated the components will not occupy the most stable equilibrium. In force driven coupling proper seating can be induced by a preload that overcomes the contact friction and causes the spherical elements to brinell out surface irregularities at the contacts.

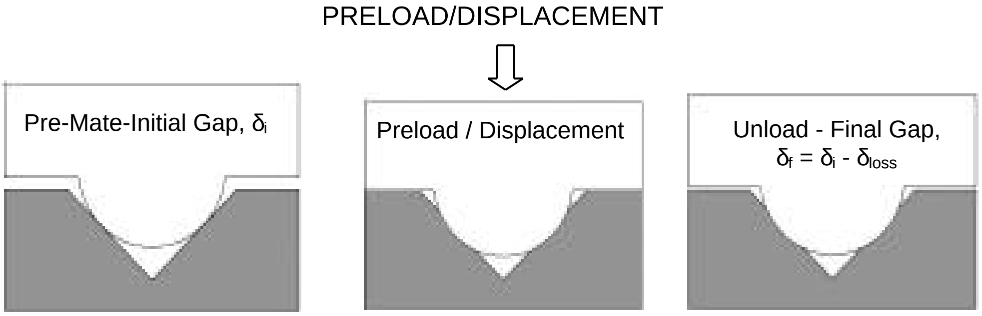



**Figure 2 Mating Cycle of QKCs**

When mating of opposed faces is desired (i.e. for sealing) one can design for displacement driven coupling. In this design, the compliance of the kinematic elements can be chosen such that a desired preload will brinell out surface irregularities and close the gap between components. On removal of the imposed displacement, all or part of the gap is restored through elastic recovery of the kinematic elements. This is necessary to maintain the quasi-kinematic nature of the joint for subsequent mates.

## DESIGN

The design and analysis of Quasi-Kinematic Couplings is moderately complex and in some cases iterative, so preference in this abstract has been given to describing the coupling and its characteristics. A list of the basic components of the design and analysis are provided below. Thorough coverage will be given in the presentation.

-Listing Constraints and Functional Requirements

-Kinematics/Geometry of the Coupling Elements

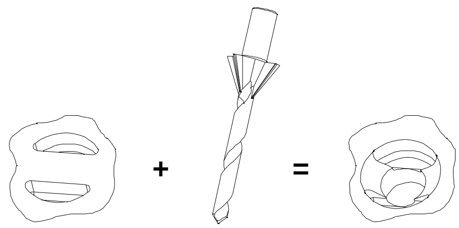
-Continuum and Compliance Characteristics

-Error Motions

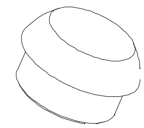
-Fatigue

-Performance Testing

## MANUFACTURING




Method for Making QKC Grooves



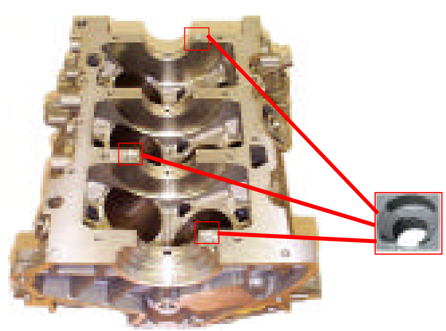
Crowned Pegs

**Figure 3 Examples of Inexpensive QKC Elements**

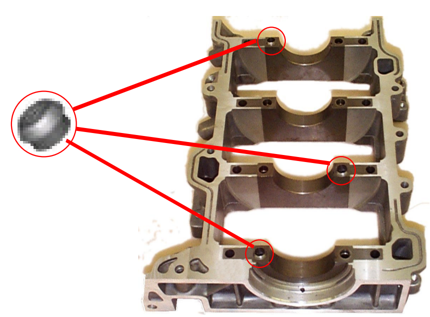
Figure 3 shows inexpensive methods for making QKC grooves and convex members. Quasi-Kinematic Grooves seats can be made by machining cast-in reliefs with a form tool. In many cases, this allows the simultaneous machining of the groove surfaces and drilled holes. Crowned pegs or balls can be pressed into or otherwise attached to the components. If crowned pegs are used, their axisymmetric geometry makes them well suited for production on screw machines. When purchased in volume, these pegs can be attained for roughly the same cost as hollow dowels.

Tolerances on the location of QKC elements are less stringent than pinned joints because crowned pegs or spheres can easily fit into conical holes which are slightly misaligned; then force them to conform during the initial deformation (Culpepper 1999). Depending upon the application, the tolerance range for QKC element placement can be three times wider than pinned joints which are intolerant of pin-hole pattern misalignment.

## PERFORMANCE / EXAMPLE



6 Cylinder Block: 3 Conical Grooves Coaxial With Threaded Bolt Holes



6 Cylinder Bedplate: 3 Spherical Shaped Pegs With Through Holes for Assembly Bolts

**Figure 4 Engine Components With QKC Elements**

The performance of QKCs will be demonstrated via a case study of an automotive engine assembly. Currently, two major components of the engine, the block and the bedplate (a monolithic part containing the main bearing caps) are aligned via eight pinned joints. The two components are bolted together, then the crank bore is simultaneously machined into each component (a half bore in each.) Afterwards, the two components are disassembled, the main bearings and crank shaft are installed between them, and the block and bedplate are reassembled (Heck, 1997). Alignment of the two components before and after machining is critical as errors in the relocation of the half bore center lines can have negative affects on bearing performance (Shigley and Mischke, 1989). Maintaining the required 5 micron alignment (Vrsek, 1997) requires the elastic averaging effect of 8 pinned joints (Slocum, 1998). These joints require 16 precision holes, thus the design has high scrap/rework rates.

Tests on quasi-kinematic couplings in this applications have measured 0.6 microns linear repeatability and 3 micro-radians angular repeatability. As a result of this change, the number of precision features required for the engine coupling was reduced by 60% and coupling cost reduced by 40% (the new coupling costs less than a dollar.) In addition, since the coupling is capable of "forming out" initial misalignment between kinematic elements, feature size and feature placement tolerances are wider (+/- 0.10 mm) than those required by the pinned joints (+/- 0.04 mm.) Although the benefits to automotive engine manufacturing will be demonstrated, its use in other applications will be discussed.

KEY WORDS: Repeatability, Kinematic Coupling, Fixtures, Design For Manufacturing, Precision Alignment, Automotive Engines, Precision Assembly, Precision Manufacturing

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