PUPS-4 Kinematic Coupling Design

Your machine will likely have to have things easily attachable/detachable

1. Design a 3D kinematic coupling (for example that could be used for example as a tool or fixturing holder on your machine). (2 pts)

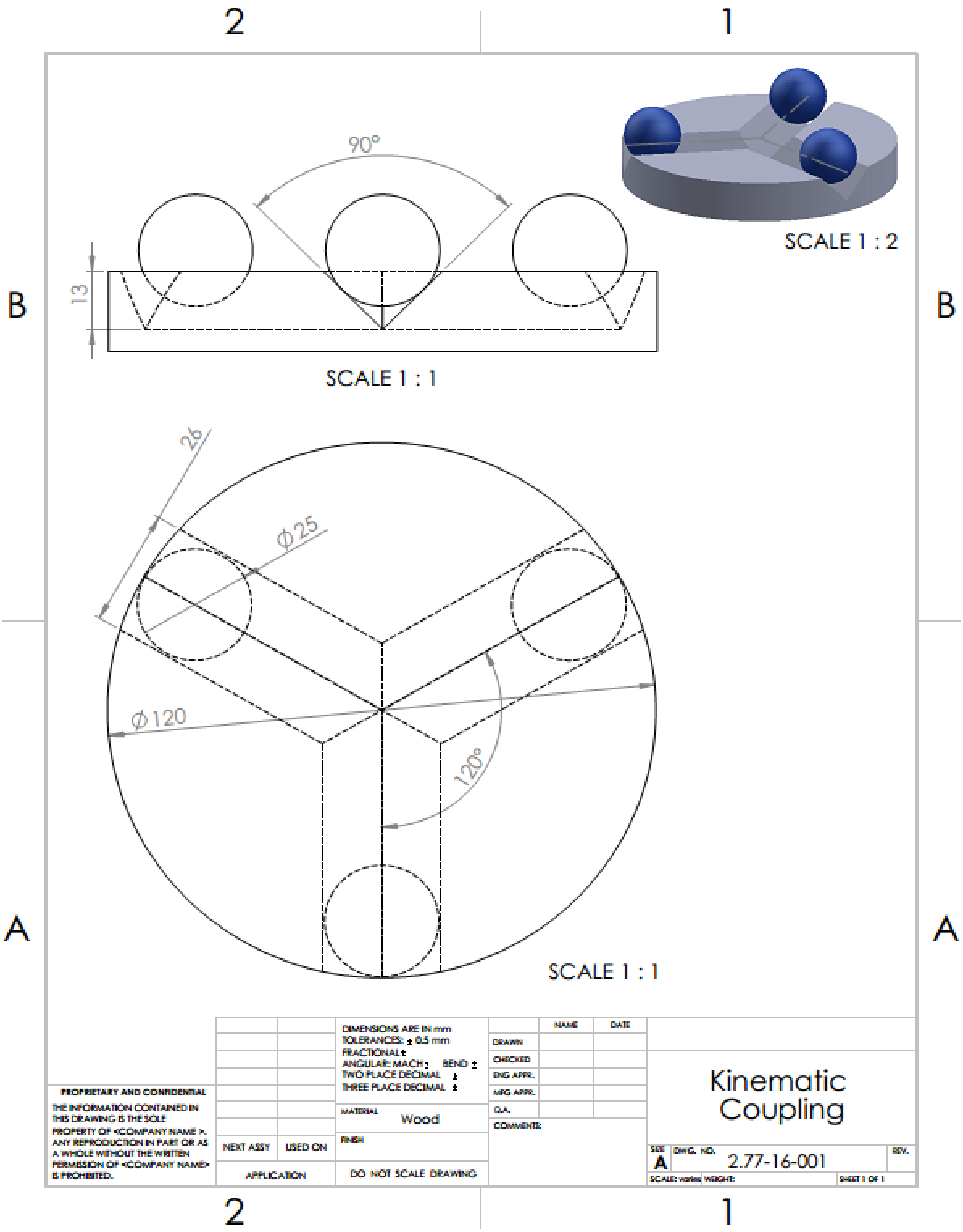
FRDPARRC

Functional Requirements	Design Parameters	Analysis	References	Risk	Counter-measures
Locate part on a horizontal plane in a repeatable manner for the XY stage.	Positioning repeatability within 10 um	Using Prof. Slocum's kinematic coupling spreadsheet	FUNdaMENTALS Chapter 3, Chapter 9 Precision Machine Design – Section 7.7		
The coupling should be rigid					

A ball in groove kinematic coupling was designed with standard parameters: 45 degree half angle (90 degree included angle) V-grooves spaced 120 degrees apart, 3 standard hemispheres. Wood was chosen as the material of choice due to its easy availability.

Kinematic_Coupling_3Groove_Design.xls								
To design three groove kinematic couplings								
Written by Alex Slocum long ago. Last modified 2012/10/28 by Alex Slocum								
Metric units only! Enters numbers in **BOLD**, Results in **RED**					**Material properties**			
Standard 120 degree equal size groove coupling? (contact forces are inclined at 45 to the XY plane. For non standard designs, enter geometry after results section)				**TRUE**	*User defined material*	***aluminum***		
					Yield stress			
System geometry (XY plane is assumed to contain the ball centers)					plastic	**3.45E+07**		
Dbeq (mm) =	**25.4**	**Equivalent diameter ball to contact the groove at the same points**			RC 62 Steel	**1.72E+09**		
Rbminor (mm) =	**12.75**	"Ball" minor radius			CARBIDE	**2.76E+09**		
Rbmajor (mm) =	**12.75**	"Ball" major radius			user defined	**2.76E+08**		
Rgroove (mm) =	**1.00E+06**	Groove radius (negative for a trough)			*Elastic modulus*			
Costheta =	**TRUE**	Is ball major radius along groove axis?			plastic	**2.07E+09**		
Dcoupling (mm) =	**625**	Coupling diameter			RC 62 Steel	**2.04E+11**		
Fpreload (N) =	**-1.5**	Preload force over each ball (negative pushes ball into groove)			CARBIDE	**3.10E+11**		
Xerr (mm) =	**0.0**	X location of error reporting			user defined	**3.50E+07**		
Yerr (mm) =	**0.0**	Y location of error reporting			*Poisson ratio*			
Zerr (mm) =	**40.0**	Z location of error reporting			plastic	**0.20**		
Auto select material values (enter *other_4* to the right)					RC 62 Steel	**0.29**		
Matlabball =	**4**	Enter 1 for plastic, 2 for steel, 3 for carbide, 4 for user defined, 5			CARBIDE	**0.30**		
Matlabgroove =	**4**	where each ball and groove is defined individually			user defined	**0.20**		
Min. yield strength (Pa, psi)		**2.76E+08**	**40,000**					
Largest contact ellipse major diameter (mm)		**2.437**						
Smallest contact ellipse major diameter (mm)		**2.433**						
Largest contact stress ratio		**0.00**						
RMS applied force (N)		**10**						
RMS stiffness (N/micron)		**0.23**						
Z displacement caused by preload (mm)		**0.037**						
Applied Z load at zero inclinatio	**-10**							
inclination angle (degrees)	**0**							
Applied force's Z,Y,Z values and coordinates				**Coupling centroid location**				
FLx (N) =	0.00	XL (mm) =	**0**	xc (mm)	0.000		XL (m) =	0.000
FLy (N) =	0	YL (mm) =	**0**	yc (mm)	0.000		YL (m) =	0.000
FLz (N) =	-10	ZL (mm) =	40	zc (mm)	0.000		ZL (m) =	0.040
Results: Hertz stresses and deformations								
Error displacements at the point of interest due to applied load (preload displacement subtracted off) (micron)								
DeltaX (mm)	0.0000		**DeltaY (mm)**	0.0000		**DeltaZ (mm)**	0.0443	
resulting rotation (degrees) wr	0.0000			0.0000				
Vector displacement (mm)	0.0443							

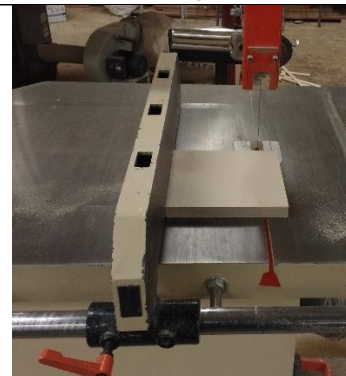
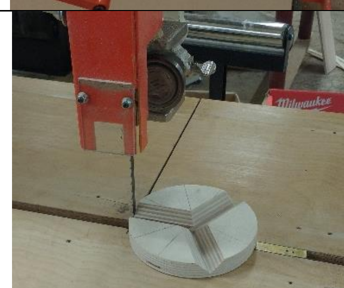
Δ_z = 45 um, RMS deflection with load = 44µm, Deflection caused by preload = 37 µm, RMS stiffness = 0.23 N/µm. The coupling was modelled in Solidworks and a draft assembly drawing was made.


2
1
B
B
A
A
90°
13
SCALE 1 : 1
SCALE 1 : 2
26
ϕ25
ϕ120
120°
SCALE 1 : 1
DIMENSIONS ARE IN mm
TOLERANCES: ± 0.5 mm
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <COMPANY NAME >. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <COMPANY NAME> IS PROHIBITED.
MATERIAL
Wood
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
Kinematic Coupling
SIZE
A
DWG. NO.
2.77-16-001
REV.
SCALE: varies
WEIGHT:
SHEET 1 OF 1
2
1

a. You cannot just “print it”: you have to make it!

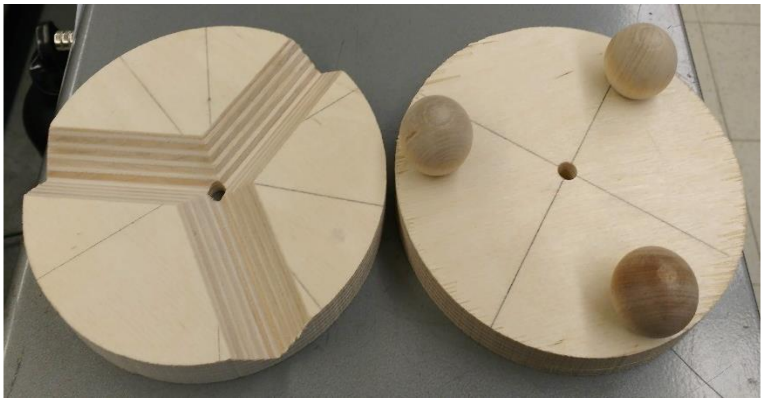
The device was made in the hobby shop by using 18 mm thick plywood sheets. I’m grateful to Mr. Ken Stone for his guidance on how to operate the machines and the manufacturing process.

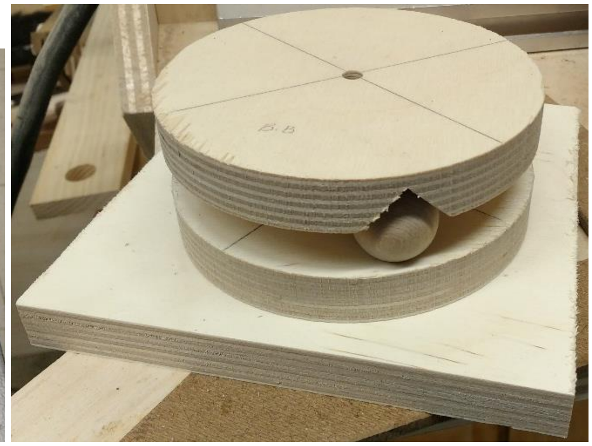
Fabrication steps:

Seq.	Process	Machine	Image
1	Cut wood into 150 x 150 mm square (2 each for top and bottom halves)	Bandsaw	
2	Cut wood into 120 mm disc (2 each for top and bottom halves)	Bandsaw with pivoting fixture	
3	Cut 90 degree included angle V-grooves	Bridgeport milling machine with indexing fixture	 
4	Glue the hemispheres in place	Wood glue and C-clamp (setting time for 15-20 min)	

2. Build and test it: (6 pts)

This is how the finished ball in groove kinematic coupling looks:





Testing:

a. Stiffness

Measured by placing the coupling on a surface plate and using a dial gauge on the top face at appoint close to center. The force vs deflection was tabulated to get the stiffness values.

Load (lbs)	**Force (N)**	**Deflection ($x\ 10^{-3}$ in)**	**Stiffness (N/µm)**
0.813	4	0.5	0.3
2.875	13	1	0.5

Which is slightly greater to the predicted value of 0.23 N/µm, but still close enough for this purpose.

b. Repeatability

Similar setup as above, the coupling was moved away from the dial, the top plate removed and then placed back. This was repeated by replacing the coupling with the same ball and grove mating (ball-1 with groove-1, ball-2 with groove-2 and so on) and then changing the groove and ball mating.

1. Same ball and groove mating- the test was repeated 10 times and the deviation was less than 1 division, ie. 0.0005 in (12.5 µm).
2. Different ball-groove mating, the maximum deviation went up to 0.002 in (50 µm).

When the matching between ball and groove was changed, the repeatability is not so good. The major reason for this may be the lack of symmetry between each of the 3 groove and coupling pairs. Since the intended use case would be to mate the ball and groove with the same matching, this should not be a concern. The design should be modified to have poka-yoke in place such that no other configuration except the matched ball and grooves would fit.

c. Accuracy

Since this isn't a motion linkage, I feel accuracy can't be quantified for this system.

3. Compare tests to predictions (close design loop). (2 pts).

Already done in section 2.

a. How would you change the design and update the spreadsheet?

I think no changes required at this point.