Addis Ababa Institute of Technology

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Mechanics of Machinery

Group Assignment-Universal Joints

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UNIVERSAL JOINTS

1. Introduction

A u-joint (universal joint) is basically a flexible pivot point that transmits power through rotational motion between two shafts not in a straight line.[i] It is a connection between two intersecting rotating shafts which are coplanar and are inclined at an angle with respect to each other.[ii] In other words, a universal joint is a positive, mechanical connection between rotating shafts, which are usually not parallel, but intersecting. They are used to transmit motion, power, or both. U-joints are used to absorb vibrations and shock in the drive line; they are also used to allow the rear/front to travel up and down.

Universal joints go by a lot of different names - U joint, Cardan or Hooke's joint - and are used to make a bent joint that can move in any direction. The most common use is shafts that work in a rotary motion.

The angle between the shafts may vary during the operation.[iii]

Currently, several mechanical, pneumatic, hydraulic and magnetic mechanisms are used to transmit power between two intersecting shafts; however, the mechanical type (universal joint) is mostly used in industry due to its low cost.[iv]

The u-joint needs to be flexible to compensate for changes in driveline angle due to the constantly changing terrain under the vehicle.

History

The original Universal joint was developed in the sixteenth century by a French mathematician named Cardan. In the seventeenth century, Robert Hooke developed a cross-type Universal joint, based on the Cardan design. Then in 1902, Clarence Spicer modified Cardan and Hooke's inventions for the purpose of transmitting engine torque to an automobile's rear wheels. By joining two shafts with Y-shaped forks to a pivoting cruciform member, the problem of torque transfer through a connection that also needed to compensate for slight angular variations was eliminated. Both names, Spicer and Hooke, are at times used to describe a Cardan U-joint.

The u-joint is considered to be one of the oldest of all flexible couplings. It is commonly known for its use on automobiles and trucks. A universal joint in its simplest form consists of two shaft yokes at right angles to each other and a four point cross which connects the yokes. The cross rides inside the bearing cap assemblies, which are pressed into the yoke eyes. One of the problems inherent in the design of a u-joint is that the angular velocities of the components vary over a single rotation.[v]

Universal joints are available in steel or in thermoplastic body members. Universal joints made of steel have maximum load-carrying capacity for a given size.

Standard u-joints aren't designed to run at extreme driveshaft angles unless they are specially constructed. As a rule of thumb, the angle of a driveshaft should not exceed 22 degrees. However, some manufacturers do make quality high-angle drives shafts that operate dependably from 22 to 80 degrees. Extreme-angle drive shafts are achieved by using a double cardan constant velocity joint. This is basically a joint with two u-joints.[vi]

2. **Types of U-joints**

1. Depending upon the number of joint:

- **Single Joint**

Single joint is one of the most basic types of universal joints. In this type, two rigid shafts are made to connect using a cross-shaped bar known as spider. There is also a U-shaped device known as yoke which is connected to the end of each shaft. The ends of each yoke are further attached to the two ends of the spider.

- **Double Joint**

A double joint is a combination of two single universal joints between two rigid shafts which allows increased degree of motion between the two ends. A double joint is flexible up to 90 degrees which is double than the ordinary basic joint.

2. Depending upon the Velocity Ratio:

- **Variable Velocity Joint**

In this type of joint, driving and driven shaft is placed in a straight line so that they may turn at the same speed. In vehicle, driving and driven shaft is inclined at an angle. The average speed of the driven shaft is half than that of the driving shaft. When the universal joint angle is increased, the speed variation in the driven shaft also increases.

- **Constant Velocity Joint**

Constant velocity joint (CV joint) allows the drive shaft to transmit power at any angle without the loss of speed. Generally, CV joint can be used in front wheel drive or all wheel drive vehicle.

The simplest and most common type is called the Cardan joint or Hooke joint. It is shown in *Figure 1*. It consists of two yokes, one on each shaft, connected by a cross-shaped intermediate member called the spider. The angle between the two shafts is called the operating angle. It Is generally, but n01 necessarily, constant during operation. Good design practice calls for low operating angles, often less than 25°, depending on the application. Independent of this guide line, mechanical interference In the construction of Cardan joints limits the operating angle to a maximum (often about 37½°), depending on its proportions.

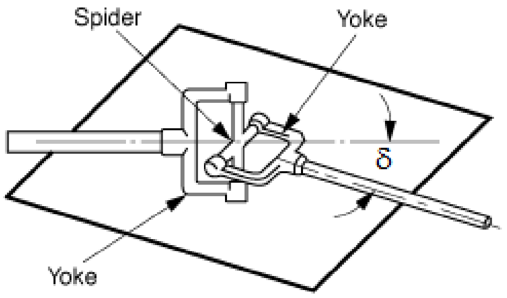


Figure 1 - Single Universal Joint

(a) **(b)**

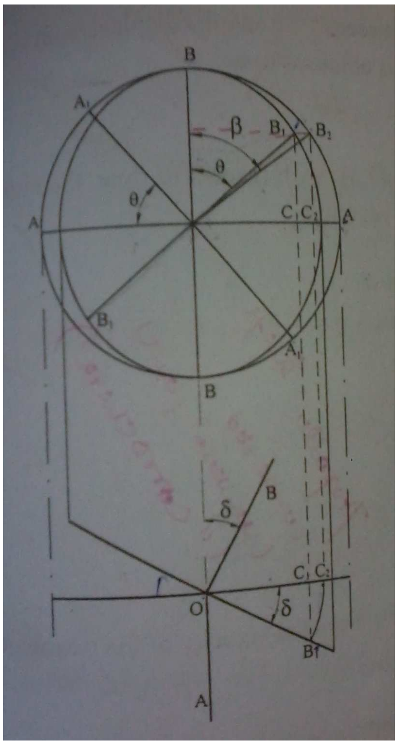
Figure 2: (a) Single U-joint and (b) Double U-joint

Single Cardan Joints[vii]	
Advantages	**Disadvantages**
Low side thrust on bearings	Velocity and acceleration fluctuation increases with operating angle
Large angular displacements are possible	Lubrication is required to reduce wear
High torsional stiffness	Shafts must lie in precisely the same plane
High torque capacity	Backlash difficult to control

3. Velocity ratio of shafts

Consider two shafts A and B which are the driver and follower, respectively. The axes of the two shafts are inclined at an angle δ from the plan view. If observed from the direction of A when the shafts rotate, A-A traces a circle while B-B traces an ellipse. The ellipse is a projection of the circle trace by b-b. [viii]

If the shaft A turns through an angle of θ from AA to A_1A_1, then the projection of BB will also turn through angle θ to B_1B_1. During this time the angle turned by shaft B is β as observed from the axis of shaft B. The projections of B_1 and B_2 are AA and C_1 and C_2.



Form the geometry of the projections,

$$\tan\theta = OC_1/C_1B_1$$

and

$$\tan\beta = OC_2/C_2B_2 = OC_1/C_1B_1$$

Combining these two equations, we get

$$\tan\theta/\tan\beta = OC_1/OC_2 = OC_1/OB_1$$

From the plan view, it can be observed that

$$OC_1/OB_1=\cos\delta$$

Thus, the relationship betweenθ, the angular displacement of shafts A and B, the angular displacement of shaft B is obtained to be

$$\tan\theta= \tan\beta*\cos\delta$$

Differentiating the equation with respect to time, the output shaft velocity can be related to the input shaft velocity.

$$Sec^2 d\theta/dt=\sec^2 d\beta/dt*\cos\delta$$

where δ is a constant.

$$d\theta/dt=\omega_A$$

and

$$d\beta/dt=\omega_B$$

The velocity relationship between the velocities of the two shafts is thus obtained to be

$$\omega_A\sec^2\theta=\omega_B\sec^2\beta*\cos\delta$$

From the trigonometric relations,

$$Sec^2\beta=1 + \tan^2\beta$$

Substituting for tanβ in equation 7.5,

$$Sec^2\beta= 1 + \tan^2\theta/\cos^2\delta=(\cos^2\delta+\tan^2\theta)/\cos^2\delta$$

Therefore, from equation 7.9 we obtain and equation relating the input and output velocities

$$\omega_A=[(\cos^2\delta+\tan^2\theta)/\cos^2\delta] * [\omega_B * \cos\delta * 1/\sec^2\theta]$$

Upon simplification, the velocity relation is obtained to be

$$\omega_A=[(1-\sin^2\delta*\cos^2\theta*\omega_B)/\cos\delta]$$

Hence, the ratio of the angular velocities is given by

$$\omega_B/\omega_A=[(\cos\delta)/(1-\sin^2\delta*\cos^2\theta)]$$

The ratio ω_B/ω_A has a maximum value when $\cos\theta \cong \pm 1$, for which $\theta=0$ or $\theta=180^o$ or any multiple of 180^o. For this condition,

$$(\omega_B/\omega_A)_{max}= [(\cos\delta)/(1-\sin^2\delta)]=(1/\cos\delta)$$

The ratio ω_B/ω_A has a minimum value when $\cos\theta=0$, for which $\theta=90^o$ or $\theta=270^o$. For this condition,

$$(\omega_B/\omega_A)_{min}=\cos\delta$$

4. Polar Angular Velocity Diagram

The velocity of the driver and follower for a complete revolution of the joint is shown on a polar angular velocity diagram. Since the angular velocity of the driver is assumed constant, it is represented by a circle. The angular velocity of the follower is shown as an ellipse, since its magnitude varies between a maximum and a minimum. The ellipse crosses the circle at four points, in which case, during a cycle the angular velocities of the driver and the driven shaft are equal. For this condition,

$$\cos\delta/(1-\sin^2\delta*\cos^2\theta)=1$$

$$\cos^2\theta=(1-\cos\delta)/\sin^2\delta=1/(1+\cos\delta)$$

Upon simplification, we obtain

$$Sec^2\theta=1+\cos\delta=1+\tan^2\theta$$

Solving for $\tan\theta$, we get

$$\tan\theta=\pm\sqrt{\cos\delta}$$

5. Coefficient of Speed fluctuation

The difference between the maximum and minimum speeds of the follower expressed as a ration of the driving shaft speed for constant angle δ between the axes of the driving and driven shafts is defined as the coefficient of speed fluctuation.

$$q= [((\omega_B)_{max}-(\omega_B)_{min})/\ \omega_A]$$

Substitution for $(\omega_B)_{max}$ and $(\omega_B)_{min}$ yields

$$q= [((1/\cos\delta)(\omega_A)-\cos\delta(\omega_A))/\ \omega_A]$$

OR

$$q= [(1/\cos\delta)-\cos\delta]$$

From the equation 7.21 the coefficient of speed fluctuation is obtained to be

$$q= \sin\delta*\tan\delta$$

For small angle δ, sinδ=δ and tanδ=δ. Hence, the coefficient of speed fluctuation is given by

$$q=\delta^2$$

where δ is in radians.

Having obtained the coefficient of speed fluctuation q, the total fluctuation of the speed is then given by

$$\text{Total fluctuation of speed} = \delta^2*\omega_A$$

6. Angular Acceleration of driven shaft

Assuming ω_A to be constant, for a constant inclination δ between the driver and follower, the angular velocity of the follower is

$$\omega_B =[(\cos\delta)/(1-\sin^2\delta*\cos^2\theta*\omega_A)]\omega_A,$$

which is observed to depend on the angular position θ. The angular acceleration of the driven shaft is then obtained by differentiating the angular speed of the driven shaft.

$$\alpha_B=-\omega_A{}^2*(\cos\delta*\sin^2\delta*\sin2\theta/(1-\sin^2\delta*\cos^2\theta)^2)$$

For the maximum angular acceleration, the acceleration term is differentiated with respect to time and set equal to zero to give the position for which the acceleration is maximum or minimum i.e.,

$$d(\alpha_B)/dt=0=d(-\omega_A{}^2*(\cos\delta*\sin^2\delta*\sin2\theta/(1-\sin^2\delta*\cos^2\theta)^2))/dt$$

Upon simplification,

$$\text{Cos}2\theta=\sin^2\delta\ (2-\cos^2 2\theta)/(2-\sin^2\delta)$$

For small values of δ,

$$\text{Cos}2\theta=2\sin^2\delta/(2-\sin^2\delta)$$

Thus, having obtained the angular position for which the angular acceleration is maximum, the angular acceleration is obtained by substituting for θ in the equation of the acceleration.

7. Double Hooke's joint

In an automobile, if only a single Hooke's joint were used, either the speed of the engine or that of the car would have to vary during each revolution of the drive shaft. However, the inertia at both ends would resist this occurrence as a result of which high stresses would occur on the transmission shaft and slippage on the tires. This problem is solved by employing a double Hooke's joint which provides a uniform velocity between input and output ends, limiting the variation of speed to the intermediate shaft.

If the driver and follower are inclined equally relative to the intermediate shaft, the fluctuation of speed will be confined to the intermediate shaft alone. The intermediate shaft can then be made short and light in order to reduce the inertia in the transmission.

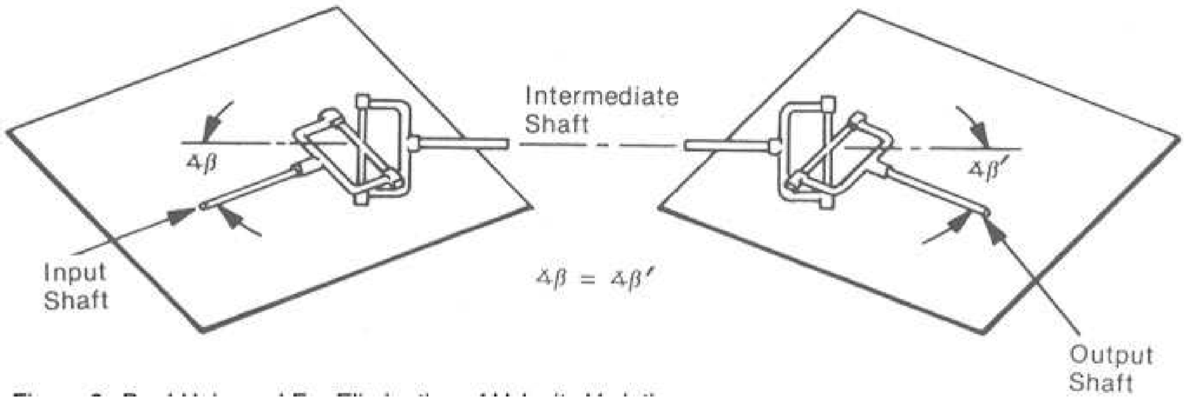


Figure 3.

For double Hooke's joint in which the forks are the same plane, the relation between ω_2, speed of the driver, and ω_4, speed of the follower, is obtained as follows. For angle θ which the driver turns through in a given time,

$$\tan\theta = \tan\gamma * \cos\delta$$

where β is the angle turned by the follower or the output shaft. From these relations, we have

$$\tan\theta = \tan\beta$$

OR

$$\theta=\beta,$$

i.e. the driving and driven shafts turn through the same angle in the same plane.

Therefore,

$$\omega_4=\omega_2$$

If the forks on the intermediate shaft are set ate right angle, the speed of the follower ω_4 will fluctuate between $\omega_2*\cos^2\delta$ and $\omega_2*(1/\cos^2\delta)$.

8. Applications

U-joints are used in a variety of applications, wherever handling significant angular misalignment is the main focus. Typical applications include: articulating mechanisms, food processing equipment, replacement for expensive gearboxes, and drives where motor position must be moved angularly off centerline of the driven unit.[ix]

Typical applications of universal joints include aircraft, appliances, control mechanisms, electronics, Instrumentation, medical and optical devices, ordnance, radio, sewing machines, textile machinery and tool drives.

Universal joints with thermoplastic body members are used in light industrial applications in which their self-lubricating feature, light weight, negligible backlash, corrosion resistance and capability for high-speed operation are significant advantages.

Universal joints of special construction, such as ball-jointed universals are also available. These are used for high-speed operation and for carrying large torques. They are available both in miniature and standard sizes.

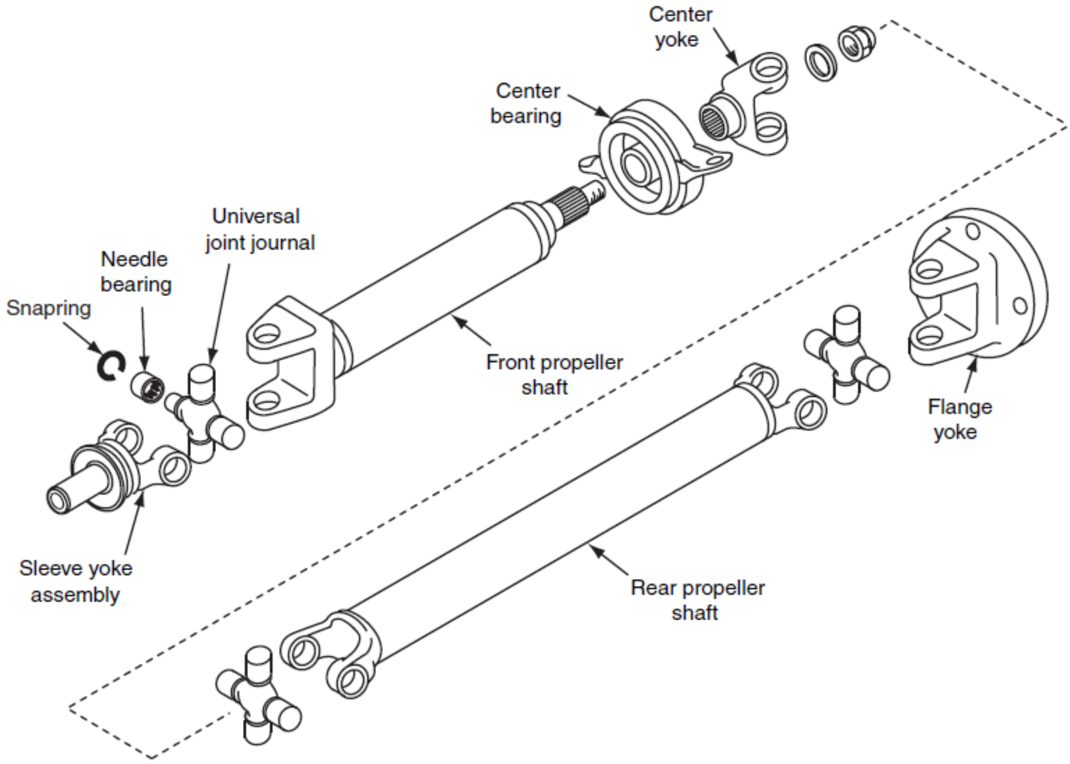

Center
yoke
Center
bearing
Universal
joint journal
Needle
bearing
Snapring
Front propeller
shaft
Flange
yoke
Sleeve yoke
assembly
Rear propeller
shaft

Figure 4

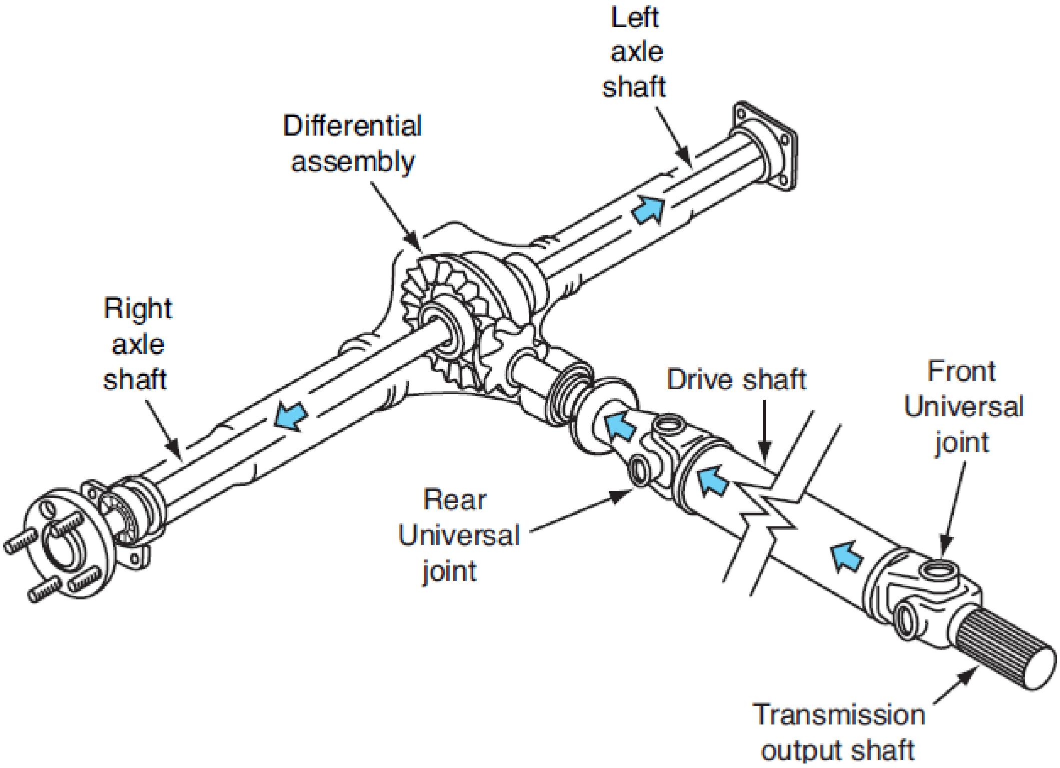


Figure 5

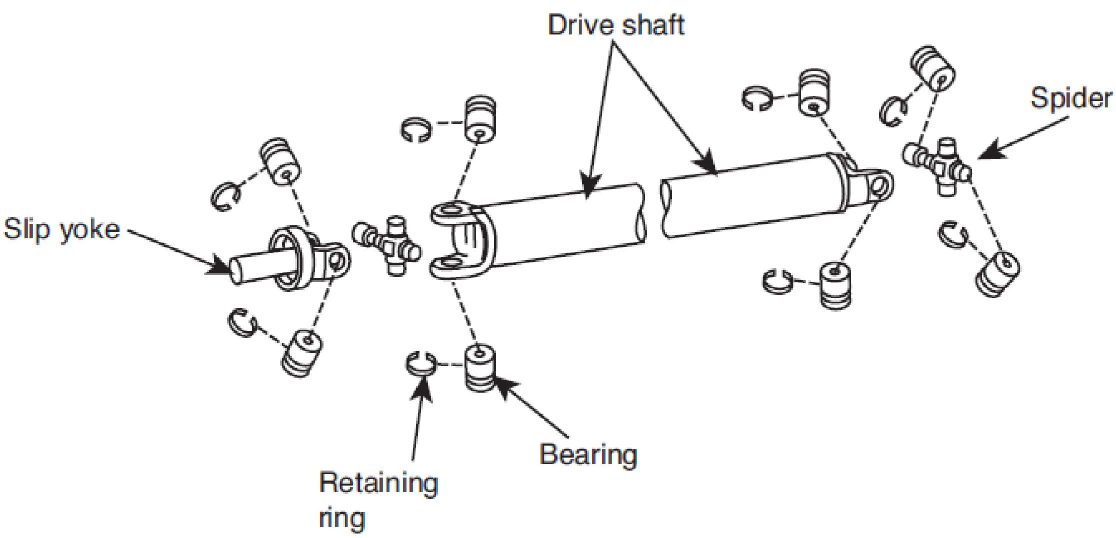


Figure 6

9. Appendix

TABLE 1 - The Effect of Shaft Angle (ß) on Single Universal Joint Performance For Constant Input Speed*

Operating Angle Between Shafts (β) Deg.	Maximum Lead or Lag of Output Shaft Displacement (ϵ), deg. Relative to Input Shaft Displacement	Maximum Angular Velocity Ratio (Ω_{max})	Minimum Angular Velocity Ratio (Ω_{min})	Maximum Angular Acceleration Ratio = $\frac{\alpha_{max}}{\omega^2}$, Where α_{max} = Maximum Angular Acceleration of Output Shaft; ω = Angular Velocity of Input Shaft, rad/sec.
0	0.000	1.0000	1.0000	0.0000
1	0.004	1.0002	0.9998	0.0003
2	0.017	1.0006	0.9994	0.0012
3	0.039	1.0014	0.9986	0.0027
4	0.070	1.0024	0.9976	0.0049
5	0.109	1.0038	0.9962	0.0076
6	0.157	1.0055	0.9945	0.0110
7	0.214	1.0075	0.9925	0.0150
8	0.280	1.0098	0.9903	0.0196
9	0.355	1.0125	0.9877	0.0248
10	0.439	1.0154	0.9848	0.0306
11	0.531	1.0187	0.9816	0.0371
12	0.633	1.0223	0.9781	0.0442
13	0.744	1.0263	0.9744	0.0520
14	0.864	1.0306	0.9703	0.0604
15	0.993	1.0353	0.9659	0.0694
16	1.132	1.0403	0.9613	0.0792
17	1.280	1.0457	0.9563	0.0896
18	1.437	1.0515	0.9511	0.1007
19	1.605	1.0576	0.9455	0.1125
20	1.782	1.0642	0.9397	0.1250
21	1.969	1.0711	0.9336	0.1382
22	2.165	1.0785	0.9272	0.1522
23	2.372	1.0864	0.9205	0.1670
24	2.590	1.0946	0.9135	0.1826
25	2.817	1.1034	0.9063	0.1990
26	3.055	1.1126	0.8988	0.2162
27	3.304	1.1223	0.8910	0.2344
28	3.564	1.1326	0.8829	0.2535
29	3.835	1.1434	0.8746	0.2735
30	4.117	1.1547	0.8660	0.2946
31	4.411	1.1666	0.8572	0.3167
32	4.716	1.1792	0.8480	0.3400
33	5.034	1.1924	0.8387	0.3644
34	5.363	1.2062	0.8290	0.3902
35	5.705	1.2208	0.8192	0.4172
36	6.060	1.2361	0.8090	0.4457
37	6.428	1.2521	0.7986	0.4758
38	6.809	1.2690	0.7880	0.5074
39	7.204	1.2868	0.7771	0.5409
40	7.613	1.3054	0.7660	0.5762

10. Bibliography

[i] Jim Oaks, TRS Magazine, Summer 2008.

[ii] Alem Bazezew, Mechanisms of Machinery, Department of Mechanical Engineering, Faculty of Technology, Addis Ababa University, July 2001.

[iii] Alem Bazezew, Mechanisms of Machinery, Department of Mechanical Engineering, Faculty of Technology, Addis Ababa University, July 2001.

[iv] Majid Yaghoubi, Ali Jafary, Seyed Saeid Mohtasebi, Design, simulation and evaluation of a new universal joint with intersecting angle upto 100 degrees for farm machineries, Australian Journal of Agricultural Engineering.

[v] Jim Oaks, TRS Magazine, Summer 2008.

[vi] Jim Oaks, TRS Magazine, Summer 2008.

[vii] Couplings and Universal Joints, www.sdp-si.com/

[viii] Alem Bazezew, Mechanisms of Machinery, Department of Mechanical Engineering, Faculty of Technology, Addis Ababa University, July 2001.

[ix] U-Joint Overview, Internet

Note*: All calculations were taken from Alem Bazezew, Mechanisms of Machinery, Department of Mechanical Engineering, Faculty of Technology, Addis Ababa University, July 2001.*