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A Slim Type Universal Joint with Lockable Axes

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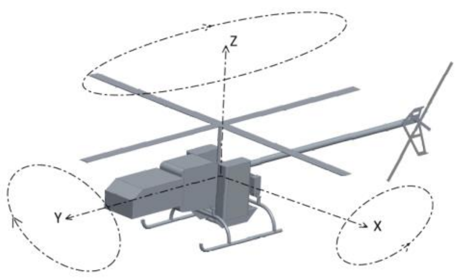
Abstract. During flight tests of unmanned air platforms, any dysfunction may result catastrophic outcomes such as collapse of the platform. In order to prevent the platform hitting to the ground, flight test equipment is used to eliminate unwanted motion of the platform due to problems arise during tests. A flight test equipment generally lets the platform turns in pitch, roll and yaw axes as well as translational axes at specified test levels. In some tests, these rotational axes are requested to be fixed and tests can be performed only at desired axes. A new lockable axis joint is designed for the control of pitch and roll axes. This joint is compared with the other possible mechanisms (universal joint, separated axis mechanism) which can be used for constructing the pitch and roll axes of the flight test equipment. Detail design procedure, range of motion and strength analyses of the new joint are presented throughout the study. In addition, further usage, possible advantages and disadvantages of the new joint are discussed.

Keywords: axis; flight; rotary; test; unmanned

[redacted] Pre-flight Test Platform for Rotary Wing Unmanned Air Vehicle

During qualification tests of rotary wing unmanned air vehicles, there is a high risk of crashing the air vehicle due to system malfunctions or mechanical failures. Therefore, qualification tests must be carried out securely by using a test platform and all flight functions must be controlled. The Figure 1 below represents a general view of a rotary wing unmanned air vehicle.

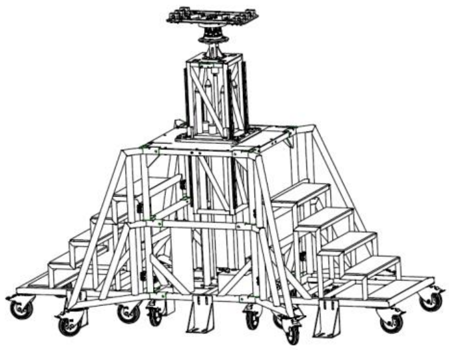
Figure 1: Rotary Wing Unmanned Air Vehicle and Motion Directions



Source: (Aselsan INC.)

The Pre-flight test platform as shown in Figure 2 consists of; a main chassis which is fixed to the ground and a mobile stairway set which can be connected/dismantled to/from the main chassis.

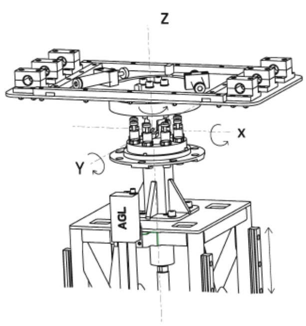
Figure 2: The Pre-flight Test Platform



Source: (Aselsan INC.)

The main aim of the test platform is to provide pre-flight testing of the rotary wing unmanned air vehicles at desired axes. There is a 4-axis mechanism in order to realize the flight tests of the air vehicle on the main chassis. The Figure 3 below represents 4 test axes, X,Y,Z rotational and Z translational axis.

Figure 3: 4 Test Axes



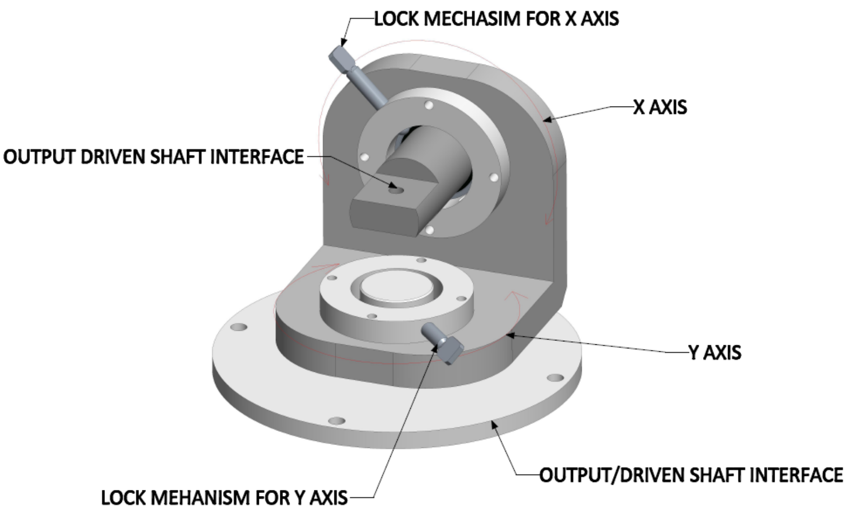
Source: (Aselsan INC.)

A hydraulic piston, which supports free weight, is used for linear motion at Z-axis in the test platform. A load cell is used to control the piston at Z axis. The platform moves such a way that the air vehicle lifts only its own weight. Other three axes (X, Y, and Z-rotational) are placed on the Z axis. These axes are driven by the unmanned air vehicle. It is sufficient to use a self-rotating bearing to ensure Z-rotational axis. Due to necessity of the test procedure, X and Y axes must be designed to limit rotation at specified angles and shock absorber must be used to prevent shock effects when the unmanned air vehicles reach the limits. Also, axes must be lockable for individual testing on each axis. Moreover, X-Y axes mechanism must be compact in order to reduce inertia loads. There can be 3 possible methods to provide rotation on X and Y axes. One of these methods is a separated axis mechanism, other method is a typical universal joint mechanism and the last method is the slim type universal joint mechanism which is the main topic of this study. Advantages and disadvantages of each type will be mentioned in the related sections as below:

1.1 The Separated Axis Mechanism

Passive gimbal system is used to achieve two axes of motion. Figure 4 below represent a passive gimbal system. This system has two separated axis which are mounted on the rotary bearing and the axes are located 90 degrees apart. These axes do not have active control and they can rotate freely. Besides, passive gimbal systems can have lock mechanism for two axes separately.

Figure 4: Passive Gimbal System



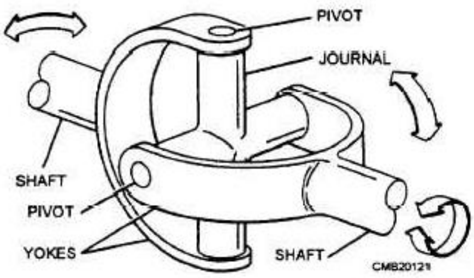
Source: (Aselsan INC.)

However, there are some disadvantages to use in pre-flight test platform. This type of mechanism is not a compact type so it is very difficult to integrate into pre-flight test system. Because of its noncompactness, it has high volume, mass, and inertia which affect the test results. Furthermore, high cost is required and labor is more than the other solutions.

1.2 The Typical Universal Joint

Universal joints have wide range of usage in all industrial scenes in order to transfer rotary motion and torque between driven and output shafts in limited space. Especially, they are designed to transmit non-axial rotary motion easily for two unaligned axis. The Figure 5 below represents a typical universal joint. [1]

Figure 5: Universal Joint



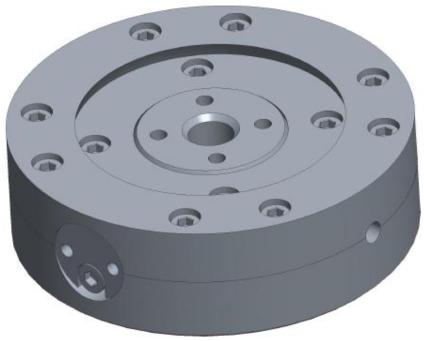
Source: (http://constructionmanuals.tpub.com/14273/css/Cross-and-Roller-Universal-Joint-179.htm)

Moreover, universal joints are compact mechanism so they are easy to use in the mechanical systems. Besides, its cost is low and it is readily available in the market. However, X and Y axes cannot move smoothly for commercial universal joints and the axes limit each other's working range as they move. In addition, due to lack of locking mechanism it cannot be used in the pre-flight test system.

1.3 The Slim Type Universal Joint

In the slim type universal joint, X and Y axes mechanism are designed by integrating into each other. In this way, a more compact and slimmer universal joint has been designed for the limited space. Due to its Compactness, low volume, low mass, and low inertia loads are acheived by this joint mechanism. In this way, inertial effects of the X-Y rotational axes are reduced. Figure 6 below represents a slim type universal joint.

Figure 6: A Slim Type Universal Joint



Source: (Aselsan INC)

Moreover, each axis has its own locking mechanism, thus X and Y axes can be locked separately. This gives the opportunity to perform tests at desired axes by locking/unlocking of each axis. Besides, X and Y axes can move smoothly and axes do not limit the range of each other.

In the light of these advantages, a slim type universal joint is more suitable to use in pre-flight test system. Detailed design of the slim type universal joint will be mentioned in the rest of the article.

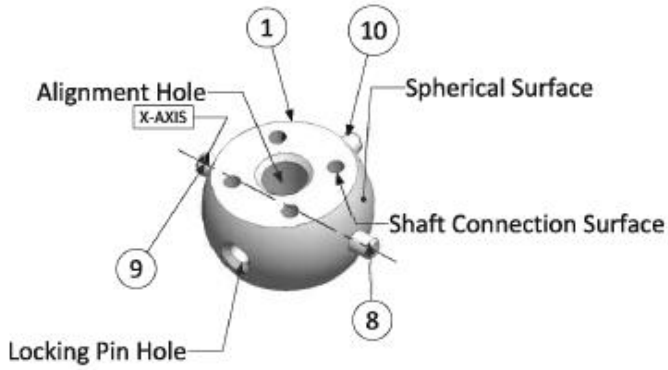
[redacted] Detailed Description of the Slim Type Universal Joint

2.1 Design of the Slim Type Universal Joint

The concept of the slim type universal joint mechanism consists of 11 parts. Three parts of them, which are called spherical core part(1), middle ring(2) and outer ring(3), form the main mechanism.

The spherical core part(1) is the innermost part of the slim type universal joint. Its outer surface is spherical, the upper and the bottom surface are straight. The spherical core part (1) has screw threads on the upper surface and an alignment hole for centering and fastening to driven/output shafts. Figure 7 below represents the spherical core part (1). On the spherical surface , three pins are attached at 90 degrees with respect to each other. Pin(8) and pin(9) are used to rotate spherical part at X-axis. Pin(10) is used to align and limit spherical part at X-axis by a radial slot which is on the middle ring(2). There is a locking pin hole which is used to lock X- axis rotation by inserting long capped pin(11) into that hole. Spherical core part(1) is placed into the middle ring(2) for the next level assembly.

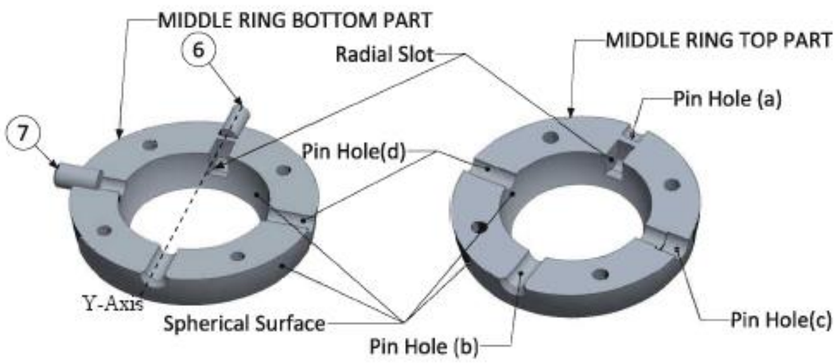
Figure 7: Spherical Part



Source: (Aselsan INC)

The middle ring (2) is formed by assembling 2 pieces which are similar to each other. Figure 8 below represents the middle rings pieces.

Figure 8: Middle Ring



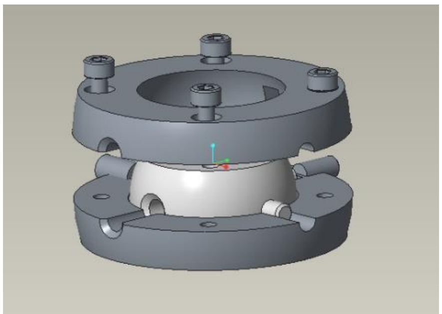
Source: (Aselsan INC)

The inner and outer surfaces of the middle ring (2) are designed as spherical. There are four pin holes in the middle ring which are positioned at 90 degrees with respect to each other. Hole (a) is not a thru hole unlike the other holes in order not to penetrate radial slot. The pin(6) is attached into hole(a) to rotate middle ring(2) at Y-axis. Inner surface of the pin hole(a) is designed as a radial slot which is used to align and limit spherical core part(1) by pin(10) at X-axis. In addition, pin hole(b) is used to rotate middle ring(2) at Y-axis by short capped pin(4) and lock spherical part(1) by changing the short capped pin(4) with the long capped pin(11) as it can be seen in Figure 10.

Pin(7) is attached in the pin hole(c) to align middle ring at Y-axis. Pin(7) slides in radial slot which is on outer part(3). Pin hole(d) is used to lock middle ring(2) by short capped pin(5).

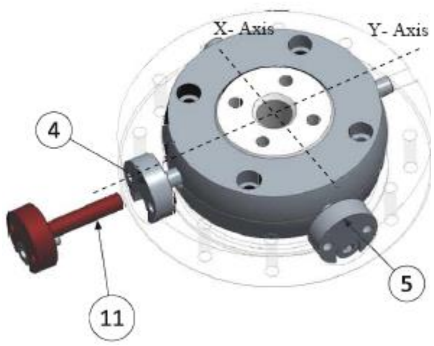
The spherical core part(1) is firstly located into the bottom part of the middle ring(2). After that, top part of the middle ring(2) is mounted on bottom part while keeping spherical core part and pins between them. For smoothness of the revolute joint, spherical surfaces of middle top and bottom must be aligned precisely. However, there is no need to use alignment pins. The pins used for X and Y rotation also align the spherical surface of middle and outer ring. Figure 9 below represents the assembly of the middle ring (2) and spherical part (1).

Figure 9: Assembly of the Middle Ring and Spherical Part



Source: (Aselsan INC)

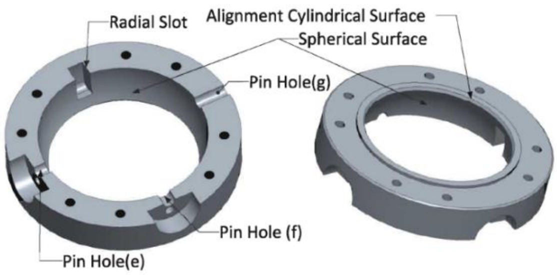
Figure 10: Outer Ring with Middle Ring- Spherical Ring



Source: (Aselsan INC)

All parts are placed on the outer ring(3) which is the outermost part of the slim type universal joint. It is formed by assembling two half pieces which have spherical inner surfaces. Outer ring has threaded holes on the upper surface and also an alignment cylindrical surface for centering and fastening to driven/output shafts. Figure 11 below represents an outer ring and its parts.There are two pin holes (e and g) which are drilled as 180-degree apart. A short capped pin(4) is fastened on the pin hole(e) and the pin(6) is precisely fitted in pin hole (g) to rotate the middle ring (2) at Y-axis. There is also a separate locking pin hole(f) which is positioned at 90 degrees with respect to pin holes(e and g). This locking process is performed by using another short capped pin(5).

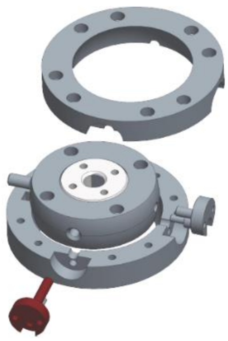
Figure 11: Outer Ring



Source: (Aselsan INC)

The middle ring and spherical core part assembly is placed into the bottom part of the outer ring. The same assembling process as in the middle ring and spherical core part is applied. Short capped pin(4) and short screw (5) are mounted followingly. Figure 12 below represents outer ring installation.

Figure 12: Assembly of the Slim Type Universal Joint



Source: (Aselsan INC)

2.2 Material Selection Criteria

In order to select the most suitable material for sub-parts of the slim type universal joint, friction coefficient, strength properties and easy accessibility conditions are investigated. Aluminum and stainless steel have easy accessibility in today's market so these materials are considered to use firstly. Table 1 shows the friction coefficients between different materials[2],[3]. According to Table 1, the least friction coefficient values is between stainless steel and aluminum. However, aluminum surface will wear out by time while sliding over stainless steel due to lesser hardness and strength. As a result, it is recommended to choose all materials as stainless steel.

Table 1: Friction Coefficient

Material	Material	Friction Coefficient
Aluminum	Aluminum	1.05-1.35

Stainless Steel	Stainless Steel	0.5
Stainless Steel	Aluminum	0.4

Source: (www.engineershandbook.com//www.tribonet.org)

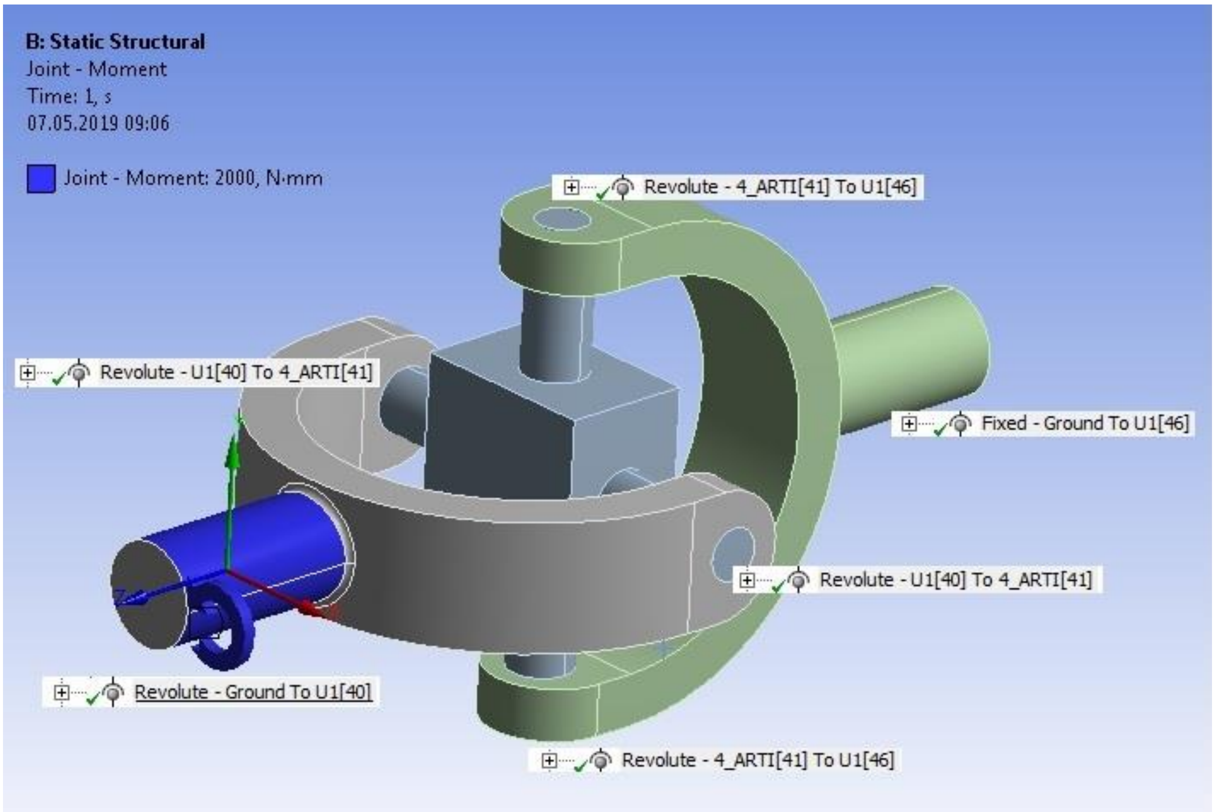
2.3 Strength Overview With Respect to an Applied Torque

Typical universal joint and the slim type universal joint are investigated with respect to stress levels on the pin connections which have the same size and the same moment arm.

2.3.1 Strength Overview of the Universal Joint

The finite element model is developed by using ANSYS [4] for the ideal case when there is no frictional losses and the angle between shafts is zero degree. Joints which are used to create the model and the applied moment can be seen in Figure 13.

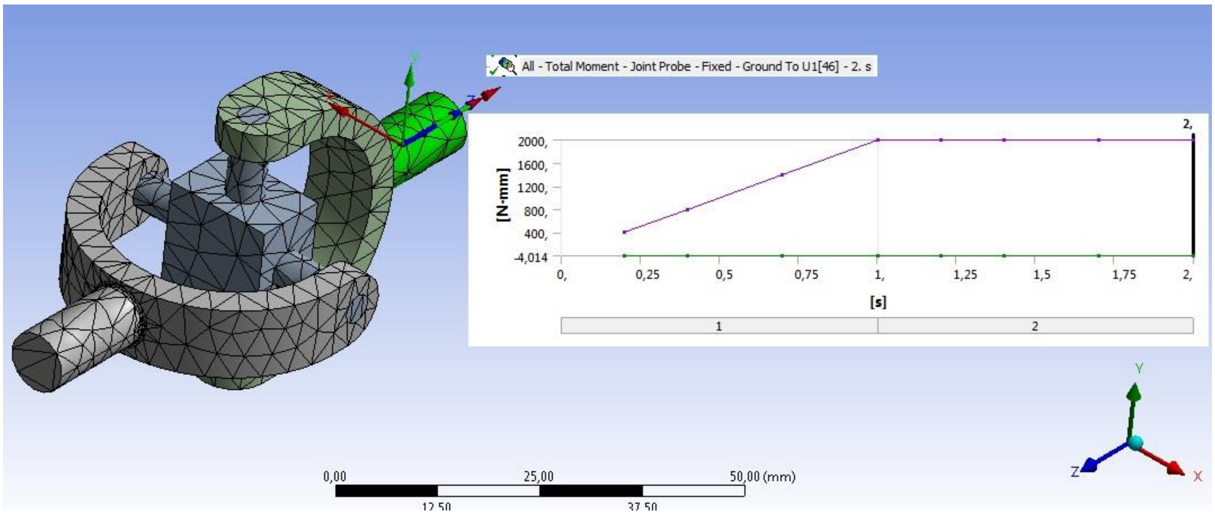
Figure 13: Finite Element Model of the Universal Joint



Source: (Aselsan INC)

As we solve the model, we can check the joint loads as they are what we expect according to statics knowledge[5][6]. If the load directions and magnitudes are similar to what we expect, we can prove the accuracy of the model. For instance, applied moment 2000 N.mm is transmitted to the shaft fixed to ground as 2000 N.mm as it is seen in Figure 14. Moreover, the summation of moments created by revolute joint forces of the cross pin and internal moments at revolute joints of the cross pin is equal to 2000 N.mm as we expect.

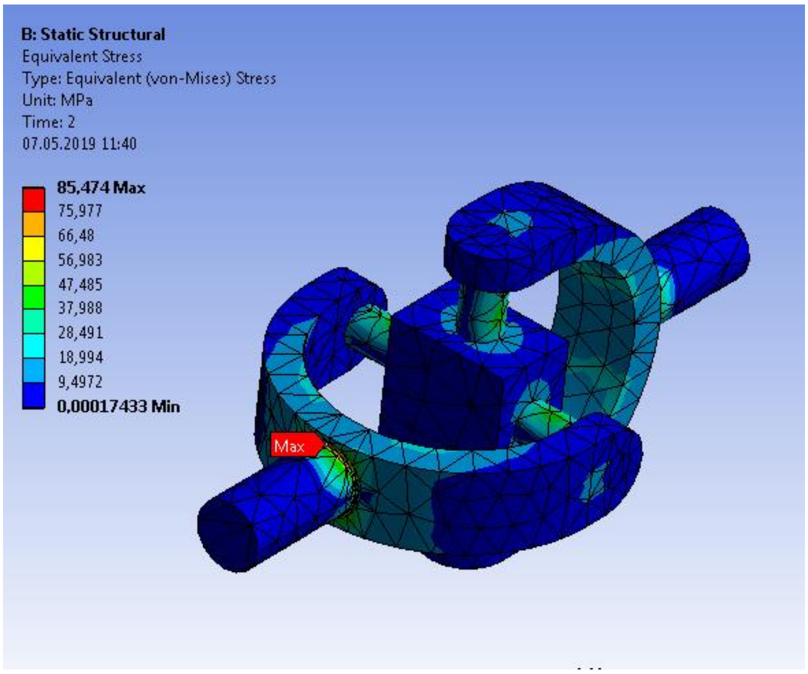
Figure 14: Finite Element Model of the Universal Joint



Source: (Aselsan INC)

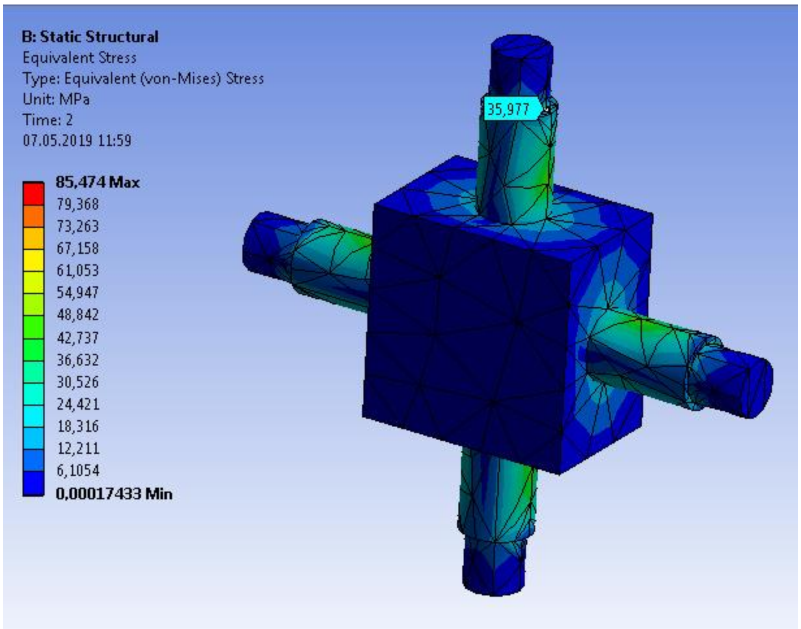
General stress distribution of the universal joint can be seen in Figure 15. However, general designs of two universal joints are not the same. Thus, only the highest stress level on the pin connections will be investigated as in Figure 16.

Figure 15: Stress Distribution of the Universal Joint



Source: (Aselsan INC)

Figure 16: Stress Distribution of the Pin Connections

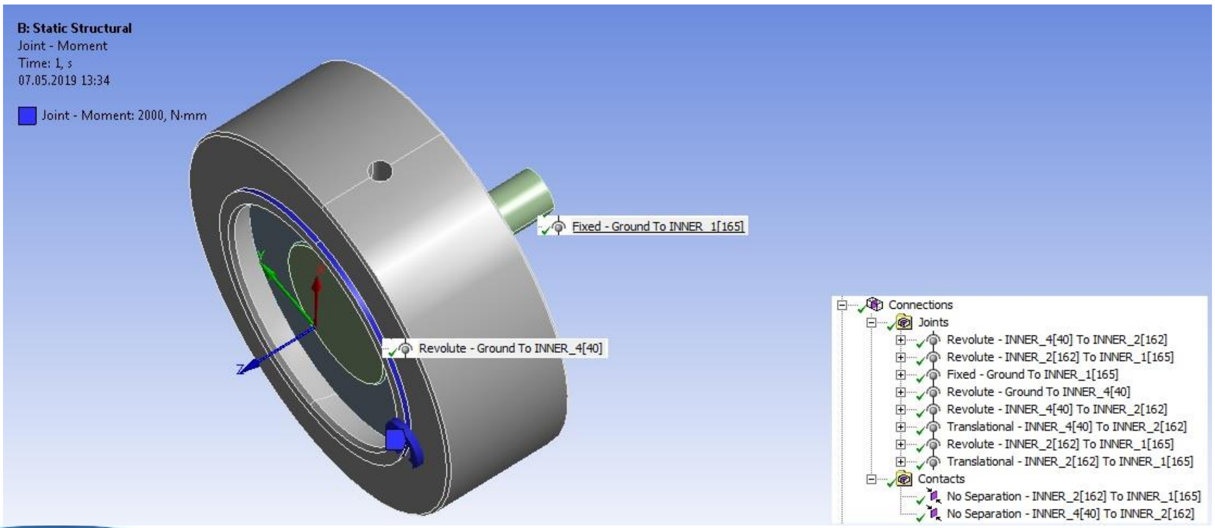


Source: (Aselsan INC)

2.3.2 Strength Overview of the Slim Type Universal Joint

Similarly, the slim type universal joint can be modeled as in Figure 17 by extracting threaded holes and counterbore holes for the simplicity of the model. Moreover, spherical surfaces are modeled as 'No Separation' contact and slots as translational joints.

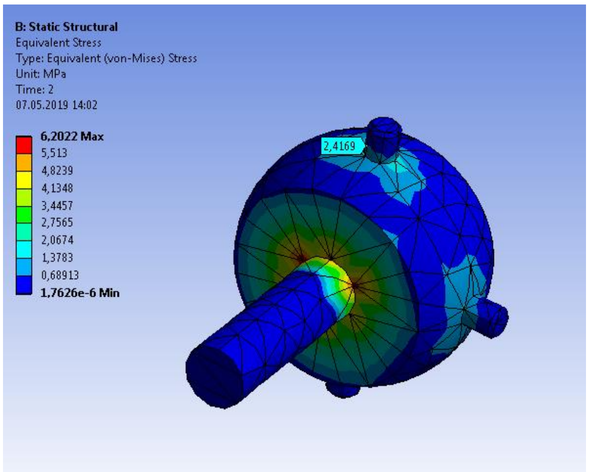
Figure 17: Finite Element Model of the Slim Type Universal Joint



Source: (Aselsan INC)

General designs of two universal joints are different but the applied moment is transmitted to fixed ground shaft by the same pins in size and moment arm. Thus, only the highest stress level on the inner pin connections will be investigated as in Figure 18.

Figure 18: Stress Distribution of the Inner Pin Connections



Source: (Aselsan INC)

As it can be seen from Figure 16 and Figure 18, highest stress level on the pins can be reduced nearly 15 times.

[redacted] Conclusion

A universal joint is used for transmitting torque and it is also used as a 2-DOF rotational joint. When a commercial universal joint is used in a mechanism as a 2-DOF rotational joint, simultaneous rotation of two axes are constrained by the contact of the joint forks. Therefore, working range of the each axis depends on the other. In contrast, working ranges of the slim type universal joint are not affected by each other. Thus, the working range of each axis remains the same in every position and locking of the joint or shock effects due to contact of the forks are prevented.

Besides, slim type universal joint can be used in kinematic designs as a 1 axis rotary joint or 2 axis rotary joint through locking pins. Locked axis can be changed by the help of versatile design. Also, custom designs can be done easily for different working ranges.

In conclusion, this alternative joint owns the possibility of further development for being a commercial product and has a potential usage in the industry.

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