



**SPECIAL  
ISSUE**

## Fluid Power Institute Tests Aluminum ZLGP

For applications where weight conservation is just as critical as zero-leak performance, aluminum Zero-Leak Gold® Plugs may provide a perfect alternative to standard ZLGP. But while EPCO has test data to prove the exceptional fatigue, burst and proof performance of steel ZLGP, no such data existed for aluminum plugs. So we decided to ask the Fluid Power Institute® located at the Milwaukee School of Engineering to evaluate the performance of aluminum Zero-Leak Gold Plugs.

Our goal was to establish minimum torque values to achieve a zero-leak seal and confirm the durability of this seal in a 1,000,000 cycle endurance test. Not only did aluminum ZLGP meet this goal – they exceeded it by successfully completing a 2,000,000 cycle test span. The following is an exact reprint of the test report\*. For more information on the test or samples to put ZLGP to the test in your application, give us a call.

### BACKGROUND

EPCO Products Inc. contracted the Fluid Power Institute® to evaluate the performance of eight different SAE fitting sizes with 3 samples of each size plug under controlled fatigue, proof and burst testing. The Fluid Power Institute® established the minimum torque values required to seal EPCO Products, Inc. aluminum Zero-Leak Gold® Plugs in SAE ORB J1926 ports at rated pressures. Testing was performed on plug sizes -02 through -12, testing (3) samples of each respective size. Once the minimum torque value had been established for each plug size a 2,000,000-cycles endurance test was performed on each selected plug size.

### PROJECT SCOPE

The objective was to determine the minimum torque values for the aluminum Zero-Leak Gold Plug fittings as supplied by EPCO Products, Inc. Three samples of plug fittings, sizes ranging from -2 to -12, were torqued to a percentage of prior test results. With the plug fittings at their minimum torque values they must complete a 1,000,000-cycle pressure fatigue test in accordance to NFPA fatigue standard T2.6.1R2-2000, a proof test in accordance to the SAE J343 4.2 MAR 1999, and a burst test in accordance to the SAE J343 4.4 MAR 1999.

### TEST PROCEDURE

The plugs were initially torqued to approximately 50% of the maximum torque values obtained from a previous test for aluminum and installed into three commercial grade aluminum manifolds that had port positions specially located for this test. Three mani-

folds were designed (6061 T6 Aluminum) with (3) ports on (3) sides and manifold # 3 had (2) ports on (2) sides. The manifolds allowed testing (3) samples of each SAE J1926 port sizes #2, #3, #4, #5, #6, #8, #10, and #12 on (3) manifolds. The rated working pressure of aluminum was 3000 psi. The manifolds were then plumbed into the impulse stand. The test setup used conventional petroleum base ISO VG 32 oil at a temperature of 100°F +/- 10°F. A relief valve was plumbed in to control the pressure required to pass the NFPA standard T2.6.1R2-2000. The manifolds were installed so that the fluid flowed through the setup. This method ensures the most uniform fluid temperature and pressure waveform characteristics, as well as efficiently bleeding out any entrained air. The test was set up to meet the NFPA fatigue standard T2.6.1R2-2000.

The fatigue testing parameters outlined by the NFPA standards T2.6.1R2-2000 were as follows:

Test Duration**	1,000,000 cycles
Cycle Rate	1.0 Hz
Test Pressure	3688 psi
Test Temperature	100° F ± 10° F
Test Oil	Benz Oil petroleum base ISO VG 32

\*\* Test continued for a total of 2,000,000 cycles.

The goal of this project at the Fluid Power Institute® was to establish torque values that successfully pass the 1,000,000 cycle Endurance Test specified in paragraph 8 of NFPA T2.6.1R2-2000. To determine torque values for EPCO anodized aluminum Zero-Leak Gold Plugs an iterative procedure was established. The plugs were anodized and dyed gold per MIL-A-8626 TYPE II Class 2 per Fort Wayne Anodizing.

Starting torque values for this evaluation were 50% of the values obtained from previous testing, test report titled "Zero Leak Gold Plug Testing"

Project number 51579\* dated 2/24/99, page 6, performed by the Fluid Power Institute at the Milwaukee School of Engineering (for torque values see Table 1).

Fitting Dash Number	Starting Torque Values (ft-lbs)
-2	1
-3	2
-4	3
-5	4
-6	5
-8	14
-10	23
-12	26

Table 1: Starting Torque Values

Each plug size torque was increased by 20% in succession until successful completion of the NFPA 1,000,000-cycle Endurance Test.

For each test, the torque value was applied to the plugs and the manifold assemblies were plumbed into the impulse chamber and the Rated Fatigue Pressure Endurance Cycle Test started. The Cyclic Test Pressure (CTP) applied will be 3688 psi for aluminum. Pressure waveforms for the 1,000,000 cycle endurance test will be in accordance with characteristics specified by paragraph 8 of T2.6.1R2-2000. The basic criteria for the wave shape is maximum rate of pressure rise must not exceed 80,000 psi/sec. The NFPA T2.6.1R2-2000, paragraph 8.4.4 states, "The Pulse Duration must be held to 100±10 milliseconds".

When a failure occurs, a new Buna nitrile 70 durometer o-ring will be installed on the plug size that failed and the torque will be increased to the next value for that size plug only. The port surface area and the plug will be cleaned to remove any fluid or



A view of the test setup.

residue prior to replacing the plug in the manifold to resume the testing. This process will be followed until all plugs pass the 1,000,000 cycle endurance test.

A failure defined by NFPA T2.6.1R2-2000

states "The inability to sustain a given load or to contain pressure in a pressure containing envelope". By the stated definition a leak would cause a failure.

The final tests conducted on the plugs will be the Proof and Burst Tests. These tests require new aluminum Zero-Leak Gold Plugs with Buna nitrile 70 durometer o-rings to be installed. The Proof and Burst Tests will be conducted in accordance with paragraphs 4.1 and 4.2 of SAE J1644 May93. Stated briefly "the Proof

Pressure Test requires (3) samples to meet or exceed a ratio of 2:1 between proof and working pressure for 60 seconds minimum". The Burst Test requirement states "(3) samples be capable of withstanding the minimum of four times working pressure without failing". During the test, o-ring Ports will be labeled and scribed with a scratch across the Zero-Leak Gold aluminum plug leading into the manifold. From this mark it can be determined if any movement of the plug in relation to the manifold has occurred. Torque values will be recorded after the test to determine if values had changed. The pressure fatigue test will then run until the plugs began to show signs of leakage or o-ring extrusion. If leakage or o-ring extrusion occurs on a plug, all three plugs of that size will be removed to examine the o-rings and plugs. If the o-ring or plug is damaged, they will be replaced. The plugs will then be torqued to a new torque value, approximately 20% greater than the previous value. This procedure will be repeated until the plugs achieve the minimum torque value needed to pass the million cycles without leaking. The impulse stand will run 24 hours a day, seven days a week for 1,000,000 cycles, except being shut down for maintenance or part failure.

After the fatigue testing is completed, the plugs will be torqued to their minimum values in high-pressure fittings. In the high-pressure fittings, the plugs will be subjected to a proof test (SAE J343 4.2 MAR 1999) and burst test (SAE J343 4.4 MAR 1999). The proof test consists of three of each size fitting passing a 2 to 1 working pressure of 3000 psi (6000 psi) for a duration of no less than 30 seconds nor more than 60 seconds. After passing the proof test the three fittings of each size will be subjected to a burst test. In the burst test the pressure will be increased at a constant rate to obtain the minimum burst pressure within a period of not less than 15 seconds nor more than 60 seconds. To pass the burst test the minimum burst pressure must be equal to or greater than 4 times the working pressure of 3,000 psi (12,000 psi).

## RESULTS AND DATA

The -2 (1/8 inch) size failed to complete the impulse test. All -2 plugs had structural failures and did not successfully complete the one million cycle test (see Appendix B).

The structural failure occurred at the fitting o-ring cross section to the outside of the hex pattern of the fitting. All other sizes, excluding the -2 size, did successfully pass the impulse testing. All of the EPCO anodized aluminum plugs passed the proof and burst to the above stated specifications.

Minimum Torque Value	
Zero-Leak Gold Plug Sizes	Anodized Aluminum (ft-lbs)
2	N/A
3	3.5
4	6.5
5	8.5
6	10.5
8	30
10	40
12	65

Table 2: Aluminum Zero-Leak Gold Final Torque Values

\*To view the entire report for the 1999 test, please visit [www.zeroleak.com](http://www.zeroleak.com). "FPI Test Data"

Anodized Aluminum Plugs	Removal Torque		Proof Testing			Burst Testing		
	Plug Sizes	Removal Torque (ft-lbs)	Average Removal Torque (ft-lbs)	Proof Pressure (PSI)	Proof Time at Pressure (sec)	Proof (pass/fail)	Burst Pressure (PSI)	Burst Mode Of Failure
2	N/A	N/A	6000	120	Passed	25092	Structural	Passed
2	N/A		6000	120	Passed	21238	Structural	Passed
2	N/A		6000	120	Passed	20457	Structural	Passed
3	6.5	8.2	6000	120	Passed	32040	Structural	Passed
3	10		6000	120	Passed	28312	Structural	Passed
3	8		6000	120	Passed	27987	Structural	Passed
4	15	12.3	6000	120	Passed	26642	O-ring	Passed
4	9		6000	120	Passed	28394	O-ring	Passed
4	13		6000	120	Passed	26961	O-ring	Passed
5	12	14.2	6000	120	Passed	27823	Structural	Passed
5	17.5		6000	120	Passed	27727	Structural	Passed
5	13		6000	120	Passed	25310	Structural	Passed
6	14.5	15.7	6000	120	Passed	23744	Structural	Passed
6	13.5		6000	120	Passed	23063	Structural	Passed
6	19		6000	120	Passed	23340	Structural	Passed
8	39	33.7	6000	120	Passed	24341	Structural	Passed
8	24		6000	120	Passed	23845	Structural	Passed
8	38		6000	120	Passed	22642	Structural	Passed
10	43	46.7	6000	120	Passed	19571	Structural	Passed
10	50		6000	120	Passed	19549	Structural	Passed
10	47		6000	120	Passed	18894	Structural	Passed
12	75	73.7	6000	120	Passed	18853	O-ring	Passed
12	80		6000	120	Passed	18887	Structural	Passed
12	66		6000	120	Passed	19023	Structural	Passed

Table 3: Aluminum Zero-Leak Gold Proof, Burst and Removal Torque data.

The final torque values to pass the impulse, proof and burst for the stated Zero-Leak Gold Plugs are listed in Table 2.

When the impulse testing was successfully finished each plug was removed from the manifold. Removal torque values were recorded and listed in Table 3. The structural failure mode listed was a failure that occurred at the fitting o-ring cross section to the outside of the hex pattern of the fitting. This failure caused the plug to crack from the o-ring groove to the inside of the fitting causing the failure (see pictures in Appendix B). There was an unknown black residue around each plug upon the completion of the impulse test. No leaks were observed and the residue was sent to a lab to determine what the substance was.

The samples were sent to SF Analytical in Milwaukee for material analysis. The final results were inconclusive; no seal material could be identified from the samples. The client requested all plugs be pressurized beyond the 4:1 requirement (12,000 psi) and continue increasing pressure until failure of the fitting or limitations of the equipment are reached. The proof test results are also listed in Table 3 with the burst test results.

## CONCLUSION

All of the EPCO anodized aluminum Zero-Leak Gold Plugs, with the exception of the -2 size, *successfully completed the 2,000,000 cycle impulse test. All of the plugs, including the -2 successfully completed the proof and burst evaluation.*

The EPCO anodized aluminum Zero-Leak Gold plugs sizes -3, -4, -5, -6, -8, -10, and -12 passed the one million-cycle impulse requirement by NFPA fatigue standard T2.6.1R2-2000 and *were run an additional one million cycles and passed with no failures.* The test ran continuously 24 hours a day, seven days a week with the exception of being shut down for equipment maintenance and failures should they occur. The marks placed on the plugs and manifold concluded that there was no movement of the plug relative to the manifold for the entire two million cycles. *The burst pressures ranged from 18,853 psi to 32,040 psi, with the requirement of 12,000 psi to pass.* The client requested all plugs be pressurized beyond the 4:1 requirement (12,000 psi) and continue increasing pressure until failure of the fitting or limitations of the equipment are reached. *The plugs also passed the proof test.*