ABCO AUTOMATION

CASE STUDY

ROBOTIC END OF ARM STRESS ANALYSIS

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ROBOTIC END OF ARM STRESS ANALYSIS

INTRODUCTION

How to build simulation models, interpret results, report the findings, and when to use traditional engineering calculations.

BACKGROUND

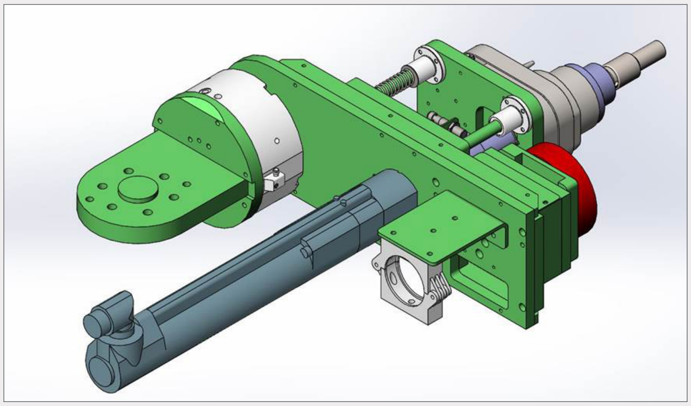
In this case study, the end effector of a robotic automation system failed and prompted a thorough review of all end effector designs. In this instance, the bolts pulled through a countebored aluminum plate, causing the end effector to fail.

PROBLEM STATEMENT

The end effector failed due to the socket head screws pulling out of the base plate. The material was cast aluminum jig plate. We needed to identify what the failure mechanism was and how to change the design to prevent future failures.

The problem statement in this case study was fairly simple: the robotic end effector had failed. An overall view of the end effector was reviewed using the SolidWorks Snipping Tool (a). The key elements were identified.

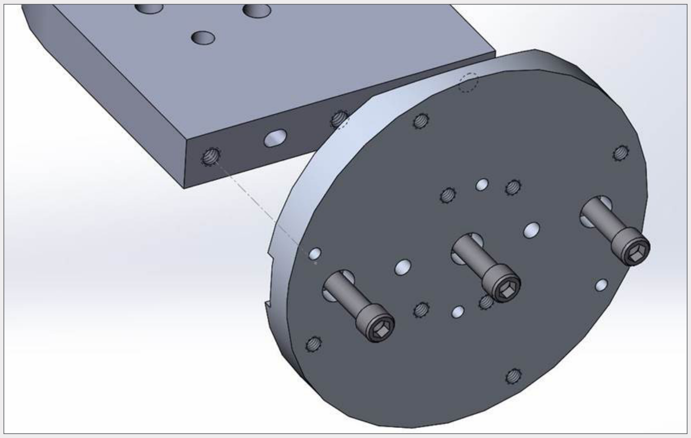
End Effector Design (a)



As the analysis was in process, the end effector parts were already changed and the new design had to be verified. The question was, "Is the new design going to work?"

A temporary assembly was made showing the two critical parts and the socket head bolts (b). An exploded view was created with sketching to help visualize the assembly. The parts had already been changed, so temporary copies were made and changed back to the previous version. The image was captured with the Snipping Tool and the temporary files discarded.

Temporary Assembly (b)



Failure Mechanism - 3/8-16 socket headscrews pulled through plate at counterbores (b)

The Mass Properties tool in SolidWorks was used to find the weight and lever arms of the end effector. The materials and models had to be checked to make sure that they were correct. If a part is imported it can be a shell or a solid mass where there are really hollow parts. If the material is not specified in the Material tab, the weight will be zero.

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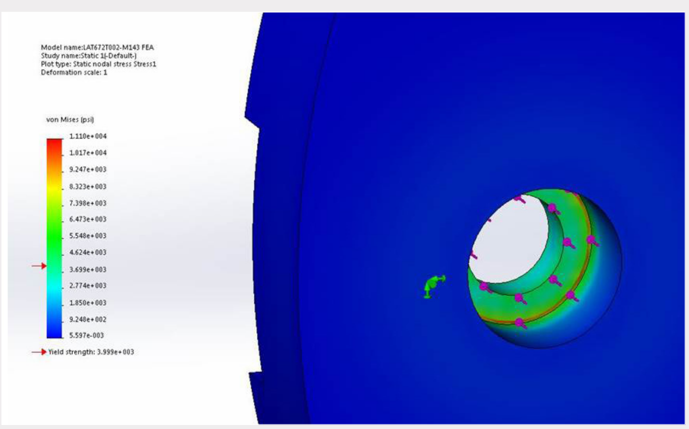
An Excel spread sheet was used to do the force calculations (c).

Loads					
	Inputs				
		Weight of End Effector	70	lbs	
		Lever arm of End Effector	13	inches	Z
		Lever arm of End Effector	7.33	inches	X
		Distance to cylinder	9	inches	X
		Spring force	25	lbs	Per spring
		Number of springs	2		
		Threaded holes	3/8-16		
		Number of holes	3		
		Width of horz	6	inches	
		Height of horz	1	inches	
		Hole spacing	2.5	inches	
		Depth of hole	0.75	inches	
	Outputs				
		Moment of End Effector	910	in-lbs	Y
		Moment of Spring force	450	in-lbs	X
		Pullout force due to gravity	607	lbs	
		Pullout force due to spring	82	lbs	
		Total pullout force	688	lbs	

Maximum pullout force = 688 lbs
Static only, no dynamic loading or impact loading (c)

The formulas are based on simple mechanics using simplifying assumptions. One such assumption is that the screw pulls parallel to the hole. A temporary copy of the base plate was made, changed back to aluminum jig plate, and an FEA performed. The failure was expected to be shear at the counterbore OD, which is what actually happened (d).

STRESS AT COUNTERBORE



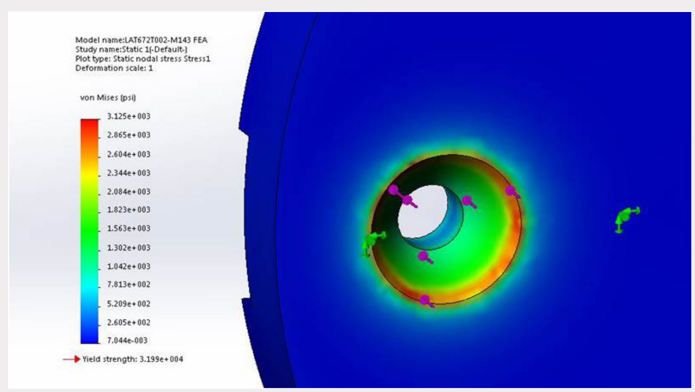
(d) Image shows detailed results.

- FEA shows 11,100 psi at screw diameter.
- Yield strength is unknown, ranges from 4,000 psi to 15,000 for cast aluminum jig plate.
- Dynamic and impact loads would increase stress.

Traditional calculations gave us conflicting results. The FEA takes into account the stress riser at the sharp radius. A small (.001 inch) extrusion was added to the SolidWorks model to define the location where the force is applied by the head of the screw. The FEA showed the actual stress to be larger than the allowable. The red arrows in the stress charts show the strength of the cast aluminum jig plate. The arrow will only be shown when the stress is greater than the strength.

The part could have been split at the bolt head OD, using the same sketch, to define the area where the load is applied. The FEA was repeated using a countersink and mild steel (e). The maximum stress was at the OD of the screw head. This showed a marked improvement in the stress levels, and also because of the different material, a marked improvement in the factor of safety.

STRESS AT COUNTERSINK

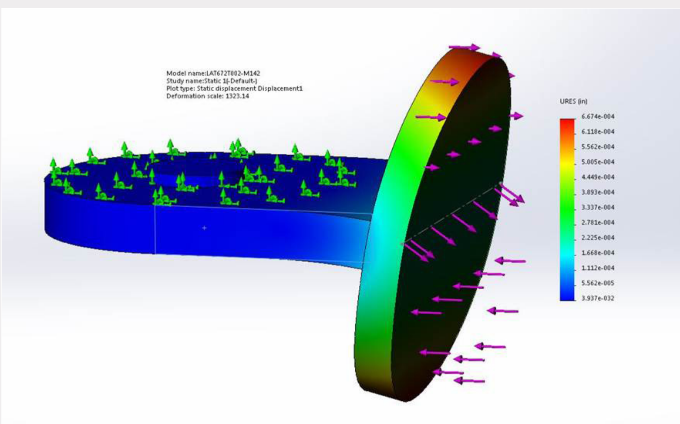


(e) Image shows detailed results.

- FEA shows 3,125 psi at screw diameter.
- Yield strength for mild steel is 32,000 psi.
- Dynamic and impact loads would increase stress.
- Factor of safety with static loads only is about 10:1.

True scale was used to show the deflection rather than the exaggerated default scale (f). A new part was made to show deflection. This is one solid part used to represent the assembly. The parts are modeled assuming that the bolts join them together as one. A fixed geometry fixture was added at the robot face defined by using a 0.001 high extrusion with the same diameter of the face. A moment representing the rest of the end effector was added at the disk.

DEFLECTION



(f) Image ʾhows detailed results.

- FEA shows about .00067 inch at top and bottom, or 0.011 degrees.
- This causes the socket at the end of the end effector to move 0.004 inch down.

The deflections were greatly exaggerated. The slope was calculated and extended to the end of the socket. Cast aluminum jig plate is dimensionally stable because it is cast and not rolled like 6061. The material can be machined off the surface without deforming, which makes it good material for making fixtures. However, the strength is very low and varies from one sample to the next and for this reason it should not be used in critical or highly-stressed locations.

One other possible failure mode was the bolts pulling out of the mild steel, which was checked thoroughly for potential failure.

The question was raised as to whether or not a gusset was necessary in the new design; however, the deflection analysis showed that it was not. The gusset goes into the "it won't hurt to add it" category.

This study only considered the static loads, but the factor of safety was about 10:1 so it is fairly safe to assume that the dynamic loads will not cause the structure to fail. To be 100% accurate, the dynamic loads should also be considered.

DISCUSSION / RECOMMENDATIONS

FEA shows that original design was likely to fail.

FEA shows that implemented fix is OK with a good factor of safety.

Cast aluminum jig plate should not be used in stressed parts.

3/8" thread pullout in mild steel is 6,218 pounds for a factor of safety of about 9:1.

A gusset is not needed.

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