Can We Reuse the Existing Gripper?

Executive Summary

Problem:

A pneumatic gripper design is proposed to grip and move aluminum handles coming off of an assembly line. The entire gripper unit is composed of an air housing unit, gripper arm connectors and gripper arms. An ABS plastic air gripper housing unit already used in the facility, along with gripper arms tailored for the aluminum handle are proposed. Several questions regarding the proposed solution include: What is the recommended air pressure to grip the handle? What is the maximum operating limit of the entire assembly? Can a material be used that will not scratch the aluminum handle? All of these questions must be answered.

Findings: ABS plastic was not suitable for the evaluated structural components under the stated operating conditions. 6061 aluminum is recommended for the Air Housing Unit and Gripper Arm Connectors. The gripper arms required a redesign to have adequate strength to support the gripping operations.

Options:

1) Aluminum with proposed design, still a high level of risk.
2) Adjust the gripper-arm geometry and specify aluminum for the purchased structural components.
3) Grip the handle in an alternate location to reduce required capacity of design.

Recommendation

Table 1: Recommended Production Settings

Item	Recommendation For Part
Air Housing Unit	6061 Aluminum
Gripper Arm Connectors	6061 Aluminum
Gripper Arm	Redesigned aluminum gripper arms with rubber contact pad

We recommend option 2. The recommended air pressure settings are 30-35 psig, but the maximum operating limit is 85 psig with adjusted gripper arm geometry.

Background

A three-jaw pneumatic gripper is being considered for a new production application. Past experience with the same air housing unit makes them a preferred choice. The air housing unit and gripper arm connectors have an ABS plastic and aluminum option. The gripper arms will be CNC machined or additively manufactured to fit the mounting points on the gripper arm connectors and geometry of the aluminum handle. The gripper arms must grab a round feature on the aluminum handle from an assembly line and transfer it to the next station. The ABS plastic air housing units and gripper arm connector are commonly used and the preferred choice.

ABS plastic was proposed to reduce the risk of scratching or marring the finished aluminum surface, while aluminum remains an alternative if greater stiffness is required. Plant personnel are asking which material combination for the Air Housing Unit, Gripper Arm Connectors, and Gripper Arms can meet the operating requirements.

The proposed gripping arm's geometry was driven by the features of the aluminum handle. The dimensions of the gripper arms were constrained by the handle geometry and required clearance during the gripping operation. The proposed gripper arms provide sufficient clearance for the gripper arms to radially center on the outer wall of the handle's shaft opening. In addition to geometry, other factors have to be considered to ensure the design can properly retain the handle. Examining the coefficient of friction, speed at which the handle travels, and changing environmental conditions are contributing factors to the reliability and success of the design.

The objective is to determine what material combination and air pressure settings for the air gripper are needed to properly grip and transport the handle.

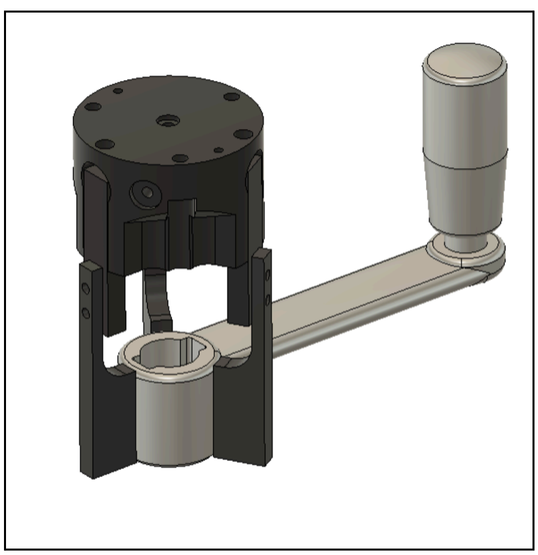

Image 1: Proposed Design To Grip The Aluminum Handle

The Business Problem

Reusing existing automation equipment can reduce both project cost and lead time however, using trial-and-error to determine whether a proposed gripper design works introduces its own major risk!

If the initial design is unsuccessful, engineers must diagnose the problem, modify the design, release new drawings, order replacement components, assemble the revised system, and test it again. Each unsuccessful iteration adds engineering hours, hardware costs, technician time, and schedule delay.

The business question is therefore:

> **Can the proposed gripper design be validated before committing to manufacturing and purchasing additional hardware?**

The goal of the analysis is not to eliminate commissioning or physical validation. It is to identify predictable design problems before they become additional design-build-test cycles.

The Engineering Challenge

Engineering questions that have to be answered before moving forward

The proposed gripper arms can fit the aluminum handle geometrically, but several questions remain unanswered before the design can be released for testing.

The first challenge is determining the gripping forces generated across the intended pneumatic operating range. These forces depend on the gripper's internal geometry, pneumatic input, contact location, and interaction between the gripper arms and workpiece.

Once the operating loads are established, the proposed design must be evaluated to determine:

- Determine gripping forces
- Determine whether the gripper arms possess sufficient structural strength
- Determine the material combination, if any, to satisfy the structural requirements
- Determine the acceptable pneumatic operating range
- Evaluate the risk of surface damage to the handle

The analysis will compare the proposed arms materials and operating conditions to identify what works, what does not, and what changes should be made before components are ordered.

The final engineering question is simple:

> **Can the proposed parts be used for this application, and under what operating conditions?**

Connecting the Engineering Challenge to the Business Problem

How concerns translate to numbers

The recommended air pressure required to grip the specific aluminum handle is 30-35 psig. At this operating pressure, the gripper arms can grip the handle, but this does not account for a decrease in gripping friction or the additional grip strength needed from changing environmental factors. As a result, we want to test beyond this range to ensure the design is robust and overcome any additional forces needed to safely grip the part. For this consideration, this design will be tested at 85 psig as standard compressed air systems can continually and comfortably operate at this pressure without any special modifications.

The business risk comes from committing to a proposed design before knowing how it will perform. If the proposed Gripper Arms or required air compressor settings are unreasonable, discovering this problem after components have been purchased, assembled, and tested is undesirable.

The engineering analysis moves those decisions **ahead of purchasing and commissioning**.

By determining whether the existing design can produce the required gripping force, the proposed gripper arms are structurally safe for the intended application, and special considerations to prevent surface damage are required, unsuitable configurations can be identified before hardware is ordered.

The financial impact of relying on physical trial-and-error can be represented as

The Money Equation.

$$Cost_{trial\,\&\,error} = N_i H_E R_E + N_s N_I [N_G C_G + N_F C_F + H_T R_T] + DC_D \qquad (1)$$

Table 1: Money Equation Inputs

Variable	Description
N_i	Number of design/build/iterations
N_s	Number of stations that use the design
H_E	Engineering hours required per iteration
R_E	Engineering Labor Rate
N_G	Number of gripper units purchased or replaced
C_G	Cost per air housing unit and gripper arm connectors
N_F	Number of gripper arm sets
C_F	Cost of Gripper Arm set per iteration
H_T	Assembly, installation, and testing per iteration
R_T	Technician build rate
D	Schedule delay
C_D	Cost per day of schedule delay

Understanding the inputs from table 1 makes it clear why a trial and error testing system is not the optimal choice and creating visibility to the multiple variables and relationships provides valuable insight into what drives the problem and where attention is needed to find a solution.

Table 2: Material Properties

Part within Model	Material
Air Housing Unit Option 1	ABS Plastic

Air Housing Unit Option 2	6061 Aluminum
Gripper Arm Connectors Option 1	ABS Plastic
Gripper Arm Connectors Option 2	6061 Aluminum
Gripper Arm Option 1	ABS Plastic
Gripper Arm Option 2	6061 Aluminum

Table 2 shows the off-the-shelf options as well as the proposed material solutions for the gripper arms. For the gripper arms, there are other material options but these two are proposed to save on cost, fabrication complexity and lead time. Now that we have the recommended air pressure settings, test case pressure settings and understand the financial landscape of this analysis, we can proceed to the analysis.

Analysis

With the engineering inputs defined, the model can now be evaluated.

This model and representative analysis have assumptions about the variables, model and parameters of the inputs. Every engineering analysis has assumptions. These assumptions are listed below for clarity and transparency.

Assumptions:

1) The model does not have any manufacturing defects or issues that would affect the material strength
2) Material properties for the stated materials are pulled from ASTM reference databases.
3) A minimum safety factor of 1.75 at the highest PSIG setting is sustainable for short term continuous operations.
4) The start location for the gripping process is the same for each part.
5) The end location for the gripping process is the same for each part.
6) The entire design is attached to a rigid mount, such as a robotic arm.
7) The aluminum handle is rigid and will not deform under the gripping load.

With the list of assumptions, the model was prepared for analysis.

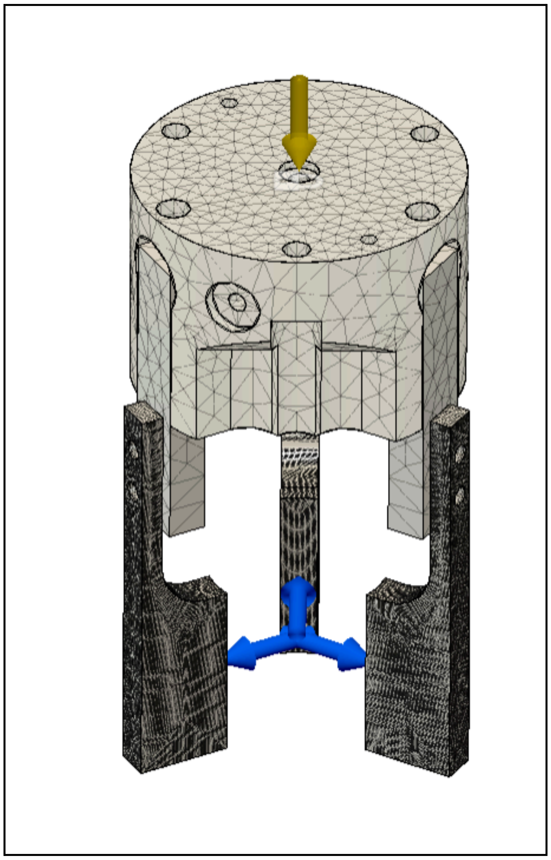

Image 2: Translating Environmental Conditions To The Model

Image 2 shows the air housing unit, gripper arm connectors and gripper arms once the air has closed the gripper arms around the aluminum handle. The yellow arrow represents the direction that gravity is pulling on the assembly. The top of the air housing unit was fixed to represent the assembly held in place by a larger assembly. The blue arrows represent the forces that are exerted on the gripper arms when they connect with the aluminum handle. Due to the cylindrical nature of the part and the face of the gripper being concave, the force will be evenly distributed on the face of each gripper arm. The arrows indicate that the force is pushing outwards. This is appropriate for modeling purposes.

While we determined 30 to 35 psi is a recommended starting point, we want to verify the upper limit of an acceptable range to ensure that the design can handle additional gripping pressure to compensate for any environmental changes. The maximum operating ceiling that can be reasonably sustained with standard compressed air equipment is 85 psig.

The first material combination tested is the proposed solution of using ABS plastic air housing unit, ABS plastic gripper arm connectors and ABS plastic gripper arms. The result of this test case can be seen in Image 3.

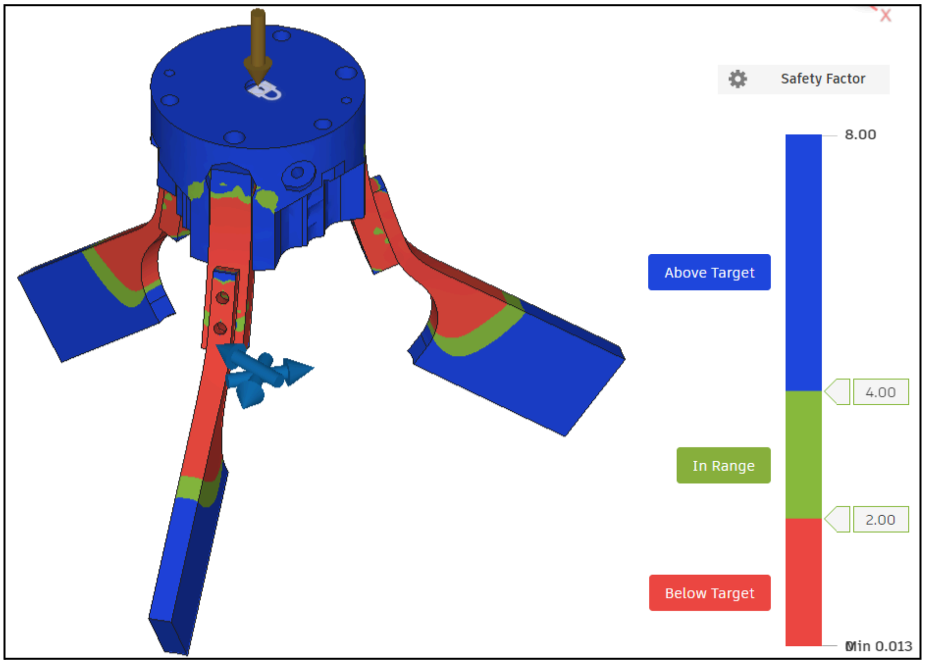

Image 3: High Stress And Excessive Deflection Occurred In ABS Gripper Arms

The large areas in red and displacement show that this material combination failed to meet desired operational conditions. Another material combination is needed.
The ABS plastic gripper arms were replaced with aluminum gripper arms. The gripper arm connectors and air housing unit are still ABS plastic. The results of testing these material combinations can be seen in image 4.

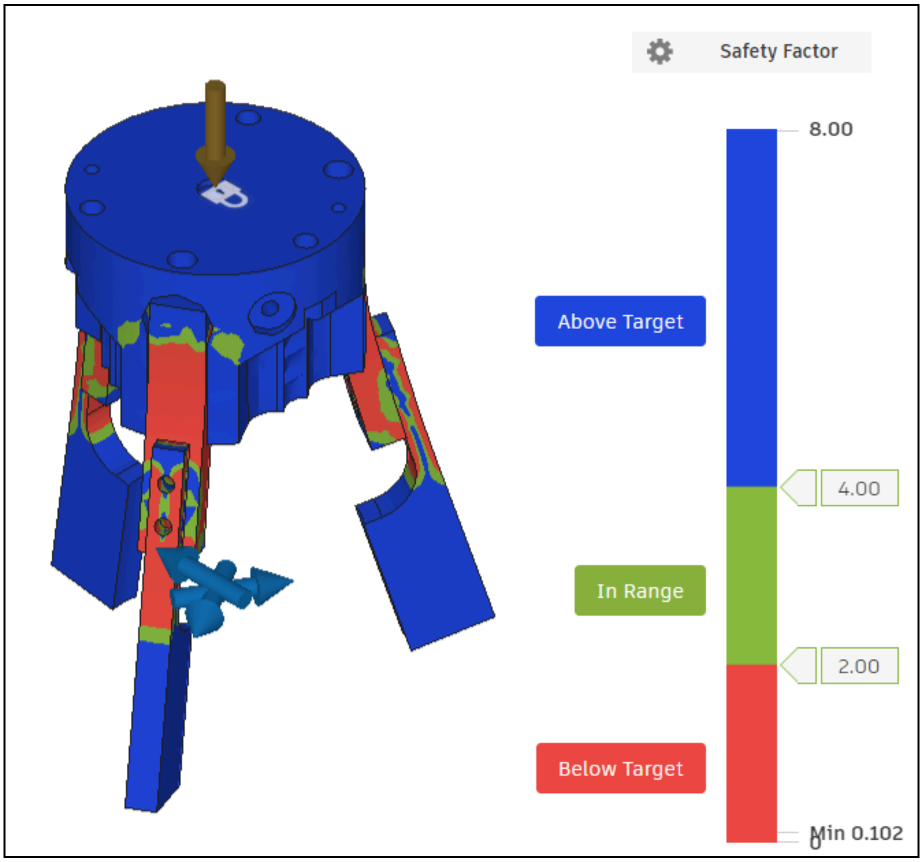

Image 4: Increasing Gripper Arm Stiffness Shifted The Load Into The ABS Gripper Arm Connectors

While upgrading to aluminum arms shows a better result than the previous material combination, this material combination is below acceptable criteria.

The next test is an all aluminum material combination under the 85 psig conditions. This combination is shown in image 5.

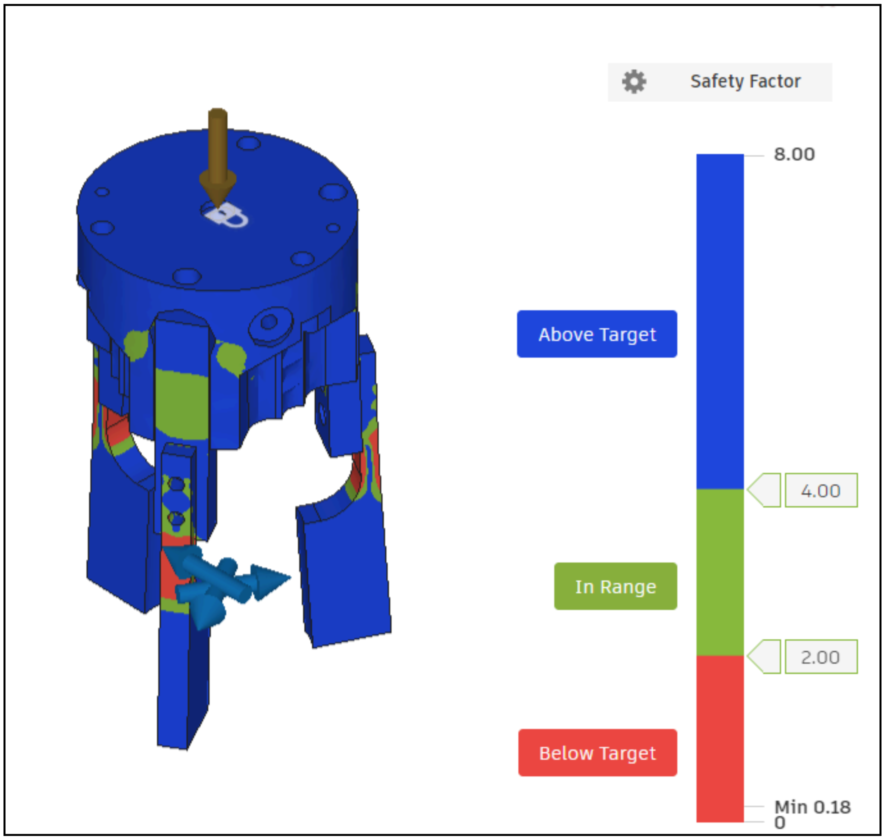

Image 5: Limiting Feature Of The Design Revealed

The all aluminum material combination is far better than any previous combination, but still not adequate for continuous operational use.

Iterating with material combinations has revealed that the proposed material considerations are not the limiting constraint for the design. The geometry is limiting the design and must be reevaluated …….

A redesign is required.

Adjusting the gripper arm geometry is the simplest and straightforward approach. The previous iterations show the location where the design is under the highest stress. Reinforcing these areas is an optimal starting point. Because ABS plastic did not provide adequate performance in the previous configurations, aluminum was selected as the baseline material for the redesign.

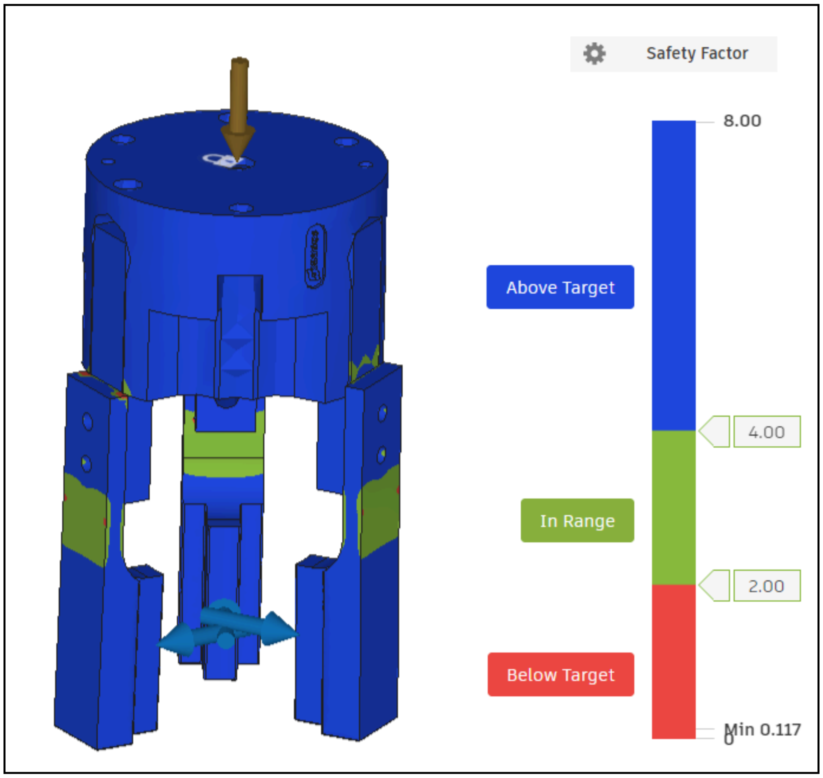

Image 6: Redesigned Gripper Arms Sustain Desired Load

The analysis from image 6 reveals that the redesigned gripper arms can sustain the desired operational conditions. Another valuable insight from the analysis is the identification of specific locations to examine during routine maintenance. Knowing the predicted high-stress regions provides specific areas to identify any issues with the gripper arms.

Key Takeaway and Outcome

The original material combinations and proposed Gripper Arm geometry did not provide a viable solution. The analysis identified the high-stress regions, and the Gripper Arms were reinforced in those areas. The redesigned aluminum Gripper Arms met the structural requirements while remaining practical to manufacture. Rubber Contact Pads are recommended to reduce the risk of marring the Aluminum Handle.

Using the money equation and estimated values shown below, the risk of a trial-and-error testing approach can be determined.

Table 3: Variables

Variable	Value
N_i	4 iterations
N_s	5 stations
H_E	8 hr/iteration
R_E	$125 per hour
N_G	0.5 units per iteration
C_G	$750 per gripper
N_F	1 Gripper Arm set per iteration
C_F	$300 per set
H_T	4 hr per iteration
R_T	$85 per hour
D	18 business days
C_D	$500 per day

Using the money equation and variables shown in table 3, an estimated cost for the trial-and-error approach.

Four engineering iterations….
+
Four gripper arm sets….
+
Replacement hardware….
+
Assembly and testing….
+
Schedule delay….

All of these items add up quickly.

Estimated Trial-and-Error Cost $33,300

The engineering analysis demonstrated that material substitution alone could not produce a viable design. The limiting factor was the geometry of the gripper arms. Once the geometry was reinforced and the appropriate aluminum construction selected, the design achieved the desired structural performance without unnecessary physical design iterations.

The objective of this analysis is not to replace commissioning, but to establish the expected operating behavior of the gripping system so manufacturing decisions can be based on quantified engineering data rather than conservative assumptions. The value of the analysis was not identifying a stronger material. It was identifying the correct design before physical iterations consumed additional time and project cost.