Project for a pneumatic test facility for high flows and temperatures

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Abstract

Pneumatic components with demanding test requirements are an important part of aeronautical MRO services. These components are mostly part the aircraft ECS systems. Test requirements of these components require facilities able to create the necessary physical conditions. The goal of this article is to size a pneumatic test facility able to test these demanding components.

This work was made in collaboration with OGMA to create in this company conditions for this type of pneumatic testing. The main constituents of the proposed pneumatic facility were sized to meet the test requirements of components belonging to the aircraft C130 Hercules. This sizing has the goal of creating a versatile test facility able to accommodate the testing of the most pneumatic components possible. A financial analysis was taken into account as well.

Key words: Pneumatic components, test facility, sizing, project, high flows, high temperatures

1.Introduction

OGMA has maintenance contracts for several C130 fleets. These contracts are normally Power by the hour. The amount paid to OGMA is, usually, just a function of the number of flight hours of the fleet. The number or types of repairs done to the aircraft do not affect, in normal conditions, the amount paid to OGMA.

Each component after being repaired and before returning to service has to be tested. This testing has to meet the working requirements (pressure, flow, temperature, etc) present in the maintenance manual of each component. At the time of this study, OGMA does not repair these demanding pneumatics in house. The repairs are being outsourced to other external companies. OGMA subcontracts these repairs, because the present pneumatic facilities can't meet the physical test requirements imposed by maintenance manuals. A decision was made to project a new pneumatic facility.

In this article there is going to be a discussion of the calculations and assumptions behind the sizing tools created in *Excel*^{TM} for this project. The layout of the new pneumatic facility and CAD will be discussed as well.

2.Test requirements

There was the need to register the test requirements for the pneumatics components currently being outsourced in order do size our system. The most demanding test conditions are the presented in Table 1.

Table 1 – Most demanding testing

PN	P (bar)	$\dot{m}$ (Kg/min)	T(°C)	t (min)
VALV 2	16	36.4	316	-
ACM1 (Line 1)	4.1	34.1	132	15
ACM1 (Line 2)	1.5	100	34	

Table 1 shows that our test facility has to be able to:

- Generate/ store enough compressed air to feed 134 kg/min for 15 min.
- Handle temperatures up to 316 °C
- Feed two independent compressed air lines

3.Layout

The general proposed layout is presented in Figure 1:

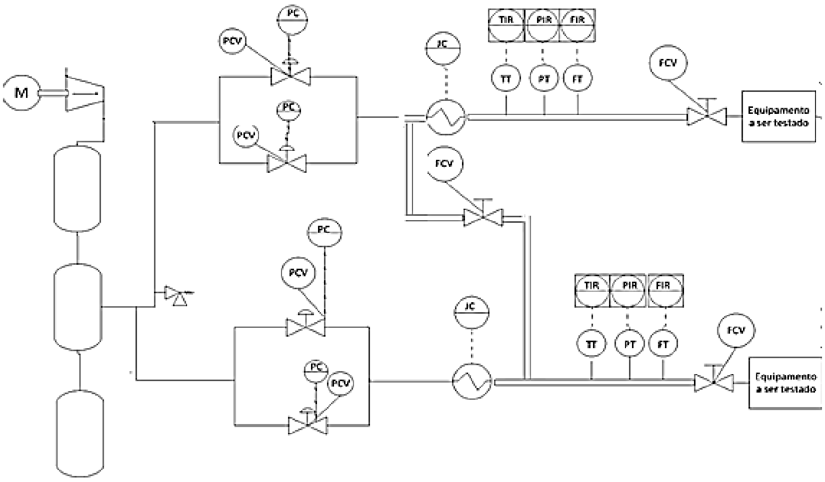

Figure 1 - General layout

This schematics show:

- An air compressor feeding three air vessels connected to each other
- Two independent compressed air lines
- Two pressure regulating valves working in parallel in each independent line
- One inline electric heaters in each line
- A data acquisition system in each line to collect pressure, temperature and flow measurements
- Thermally isolated piping after the electric heating

4. Location CAD

Ten years ago OGMA had a contract for the maintenance of Puma helicopters. The engines of these helicopters were tested in a facility called Turmo. OGMA no longer has the contract for the maintenance of helicopters, so this test facility is now deactivated.

This test facility already includes:

- 12 m by 5m chamber acoustically isolated
- Remote control room with a window to the test chamber. This window has three layers of ballistic glass.
- 2 ton crane
- Test bed
- Air extraction
- Proximity to 30 bar air vessel (less than 20 m)

Turmo is an ideal location for our new pneumatic testing facility, because it already has the require infrastructures, cutting dramatically the budget for this project. The plan was made to design a pneumatic test facility in Turmo, without impairing its ability to test helicopter engines. A CAD (Figure 2) was made in *Solidworks*^{TM} to get an idea of piping layout and length.

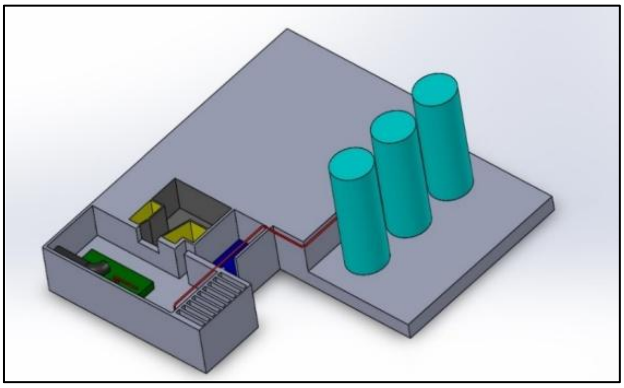

Figure 2 - CAD

From this CAD the following piping data was determined, given in Table 2.

Table 2 - Pipping length

	Length (m)
Cold piping branch (before electric heating)	6
Hot piping branch (after electric heating)	17

5. Pressure regulating

The function of a pressure regulating valve is to reduce the air pressure from the air vessels to the pressure required by the component to be tested. The valves control air flow and pressure by controlling its opening which in turn allows more or less air through. The factor used to characterize every component testing is named Kv. This factor takes into account the pressure drop required as well as the mass flow needed.

$$K_v = \frac{\dot{m}}{109.6P_1(1 - \frac{x}{3x_{TP}})F_P}\sqrt{\frac{T_1 Z}{x M_W}} \qquad (1)$$

Where $\dot{m}$ is the mass flow of air, x is the pressure ratio, x_{TP} is the corrected critical pressure ratio, T_1 is the initial air temperature, $\mathbf{Z}$ is the air compressibility and M_W the molecular weight of air and **Fp** is the piping correction factor.

Every pressure regulating valve has a value of Kvs, which is the maximum theoretical value of Kv for a valve with at 100% opening. A pressure control valve can control a range of Kv values, which are usually given in a percentage of its Kvs (%Kvs).

There are three main characteristics of pressure regulating valves:

- Equal%
- Quick opening
- Linear

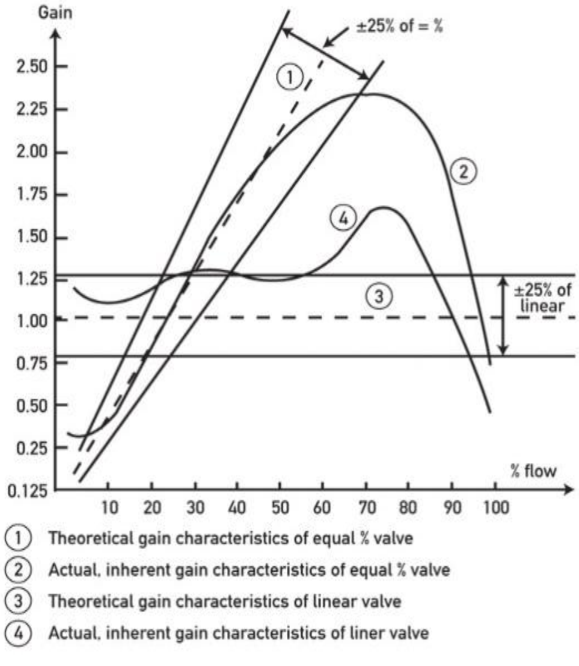

Figure 3 - Pressure regulating valve gain

These characteristics of valves differ in terms of the stroke vs Kv characteristic.

There is a controllable range of Kv for every control valve. This range can be found by comparing the theoretical loop gain of the valve with the real value of this gain. Because the manufacturing tolerance of the plug is about 10% to start with, and typical instability is about 5%, the valve should not be used near the two ends (0% and 100% stroke). Figure 3 shows one recommendation, suggesting that the theoretical (line 1, dotted) and the actual installed (line 2, solid) gain-to-load relationship of an iso% valve should be within 25%. The actual (solid) line stays within 25% of the theoretical (dotted) between 5% and 70% of Kvs. (*Lipták, 2013)*

An equal% valve guarantees a broader range of controllable Kv, this valve will be our choice because we have a wide range of test requirements. Pressure regulating valves don't function out of the 5-70% Kvs range. One pressure regulating valve can't control all the component testing. In the Table 3, it can be seen that the maximum and minimum value of Kv we need to control. (*Lipták, 2013)*

Table 3 - Component tesing Kv

PN	$\dot{m}$ (Kg/min)	P1 (bar)	P2 (bar)	Estimated Kv
ACM1	9.1	30	16	1.1
VALVX	134	10	4.1	40.7

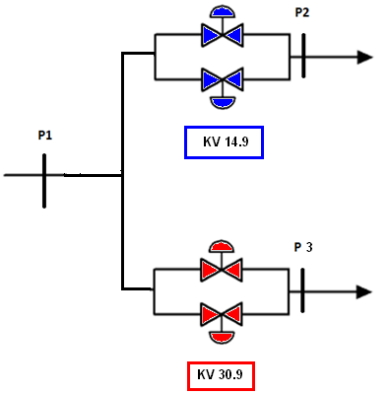

Figure 4 - Regulation valve layout

A system able to handle all the test requirements has to work with more than one valve working. The solution is to have two different branches of piping with two valves in each branch working in parallel (Figure 4). This way our system is able to control Kv ranging from 0.74 to 43.26. The valves selected are presented in Table 4.

Table 4 - Chosen pressure regulating valves

Valve type	Globe	
Kvs	14.9	31.0
Controlable KV (5%-70% Kvs)	0.74 - 10.40	1.54 –21.68
Characteristic	Equal%	

The noise produced by pressure regulating valves is an important issue, because this noise can easily exceed 100 dBA. Calculations were done accordingly with the norm IEC-60534-8-3. This norm uses the free expanding jet theory and makes approximations for transmission and velocity losses.

$$L_{pAe} = 5 + L_{pi} + TL + L_g \tag{2}$$

Calculation showed that our system can reach noise pressure level of 112.39 dBA, 10 meters form the valves. This noise pressure level is enough to make us consider acoustic shielding.

6. Heater

High-capacity electric in-line air heaters, as an integral part of a compressed air system, are used throughout the aviation and aerospace industry for R&D simulation of the high-temperature and high-pressure conditions produced by an aircraft turbofan compressor. Open-coil electric heaters provide the most optimum heating solution for rig testing as compared with traditional sheathed ('tubular') heating elements. The preferred solution for air or gas heating is to use an open coil heater, which allows the air stream to make direct contact with the heater element, greatly improving the heat transfer. (Hargreaves, 2015).

Electric heater manufactures usually oversize their hearts by 18% in terms of power.

$$\dot{Q} = 1.18\, \dot{m}_{ensaio} cp(T_{ensaio} - T_{exterior}) \tag{3}$$

Where $\dot{Q}$ is the heating power, cp the air specif heat, T_{ensaio} and $T_{exterior}$ are the final and initial temperatures. To meet all our requirements, we will need two 200 kW heaters.

7.Piping

A decision was made to have a 4'', AISI 304L piping, because this type of piping is readily available in the market. Piping thickness was sized accordingly with the norm ASME 31.1. This norm specifies the piping thickness with the flowing equation:

$$esp._m = 1.143 \left[\frac{PD}{2(S_h E + PY)} + C\right] \tag{4}$$

The final results are presented in Table 5.

Table 5 - Piping thickness

	Thickness (mm)
Cold piping branch	2.0
Hot piping branch	2.9

8.Thermal isolation

For the sizing of the thermal isolation in the piping hot branch there was the need to solve a complex problem of thermal conduction.

In this problem we have three different types of heat transfer:

- Internal flow (Flow inside of piping)
- Radial conduction (piping walls and thermal isolation)
- Free convection (around the thermal isolation)

To solve this problem we simplified the problem by constructing an electric analogue (Bergman et al., 2011).:

$$qT = \frac{T_{m1} - T_{\infty,3}}{\frac{1}{h_i 2\pi r_1 L} + \frac{\ln(r_2/r_1)}{2\pi k_A L} + \frac{\ln(r_3/r_2)}{2\pi k_B L} + \frac{1}{h_3 2\pi r_3 L}} \tag{5}$$

In this simplification we have to admit a constant surface temperature along the whole piping length. This analogue leads us to an iterative calculation. The thermal isolation chosen was a 5cm thick layer of Insulating cement around the piping. Calculation showed that this thickness of isolation cement is enough for the thermal needs of our system.

9.Compressor and air vessels

OGMA already has a 20m^3 30 bar air vessel that is available for being used in the new pneumatic facility, but there is no air compressor in OGMA able to feed this air vessel. A system of compressed air vessels and air compressors had to be sized in order to meet the test requirements. This system has to be able to meet the test requirements for the ACM1 testing. The following equation was derived using the perfect gas law in order to obtain the air compressor delivery and the air vessel capability:

$$t_{teste} = \frac{\frac{V}{RT}(30 \times 10^5 - P_{min})}{\dot{m}_{ensaio} - \dot{Q}_{FAD} \times 1.2} \tag{6}$$

To meet the test requirements of ACM1 testing and using the current 20 m^3 air vessel we would need a 5159.8 m^3/h FAD, 30 bar compressor. Calculations accordingly with the reference Hall, 2012 showed that this compressor would require 833.48 kW. OGMA's electrical system can't handle this much power, so a decision was made to have more air vessels instead of a powerful air compressor. This final system sizing is presented in Table 7.

Table 6 - Compressor and air vessels

Compressor	806 m^3/h FAD, 30 bar
Air vessel	20+60 m3, 30 bar

10.Pressure loss

Pressure loss calculations were made in section of the piping leading from the air vessels to the pressure regulating valves. The requirements for the testing of the ACM1 where used in this calculations (Table 7)

Table 7 - ACM 1 test conditions

$\dot{m}$ (kg/min)	134
T (ºC)	20
D (mm)	114.3
L(m)	17
P (Bar)	30

For line losses the Darcy-Weishbah equations was used (Mendes, 2006)*:*

$$\Delta P = \frac{\rho f L v^2}{2D} = 2133.18\ Pa$$

For losses in the piping 90º turns the Two K method was used (Mendes, 2006):

$$\Delta P = \frac{K_1}{Re_D} + K_\infty\left(1+\frac{1}{D}\right)\frac{\rho v^2}{2} = 0.0029\ \mathrm{bar}\ ;\ \mathrm{K1} = 800;\ \mathrm{K}\infty = 0.4$$

In both cases the pressure losses are not relevant.

11.Conclusions

The outsource dependency of OGMA for the repair of demanding pneumatic components is due to its inability to meet testing requirements by its current facility.

Turmo facility has all the conditions to be upgraded to test pneumatic components.

Pressure losses are negligible.

Materials chosen for piping and thermal isolation may be not the most economical ones. The tools design for the calculations can do quick calculations for different options

Open Coil technology is the state of the art in heating of compressed air.

It is preferable to store more compressed air than generating during the testing, because a high capacity air compressor consumes a relatively large amount of electric power.

Calculation for the pressure regulating valves used a general theoretical model. Each manufacture has its own calculation software, it is advisable to contact with the manufacture directly in order to make a decision regarding pressure regulation.

For future work it's advisable to consider a computerised data acquisition system to collect all the testing parameters remotely.

12.References

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