# Compression and Ultimate Pressure of Turbomolecular Pumps

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Graphs of “high-vacuum pressure as a function of backing pressure” (“$p_{HV}$ *versus* $p_{VV}$”) and “compression as a function of backing pressure” (“$K$ *versus* $p_{VV}$”) are presented. The performance of any turbomolecular pump can be fully and reliably evaluated with the aid of these graphs.

The close relation of ultimate pressure with compression is discussed using analytical functions which excellently describe the pressure dependence of the compression.

International Workshop on

**Extreme High-Vacuum Application and Technology**

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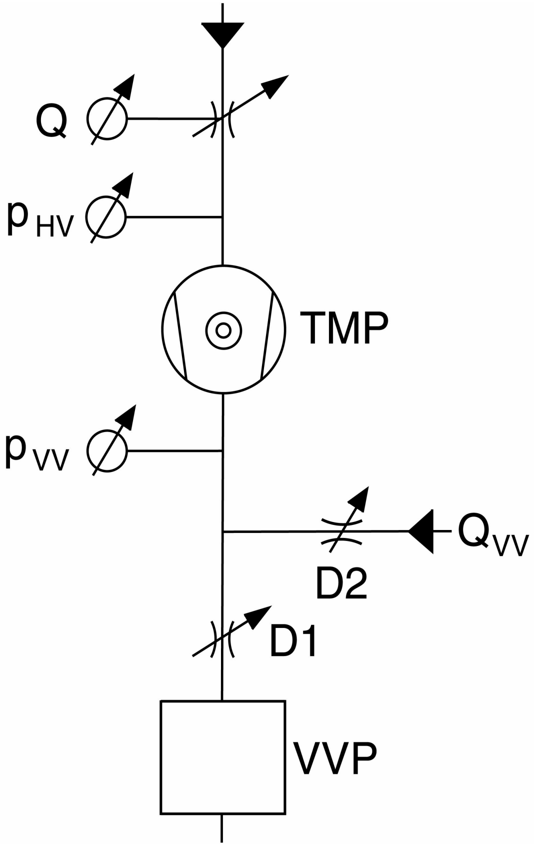
# Compression and Ultimate Pressure of Turbomolecular Pumps

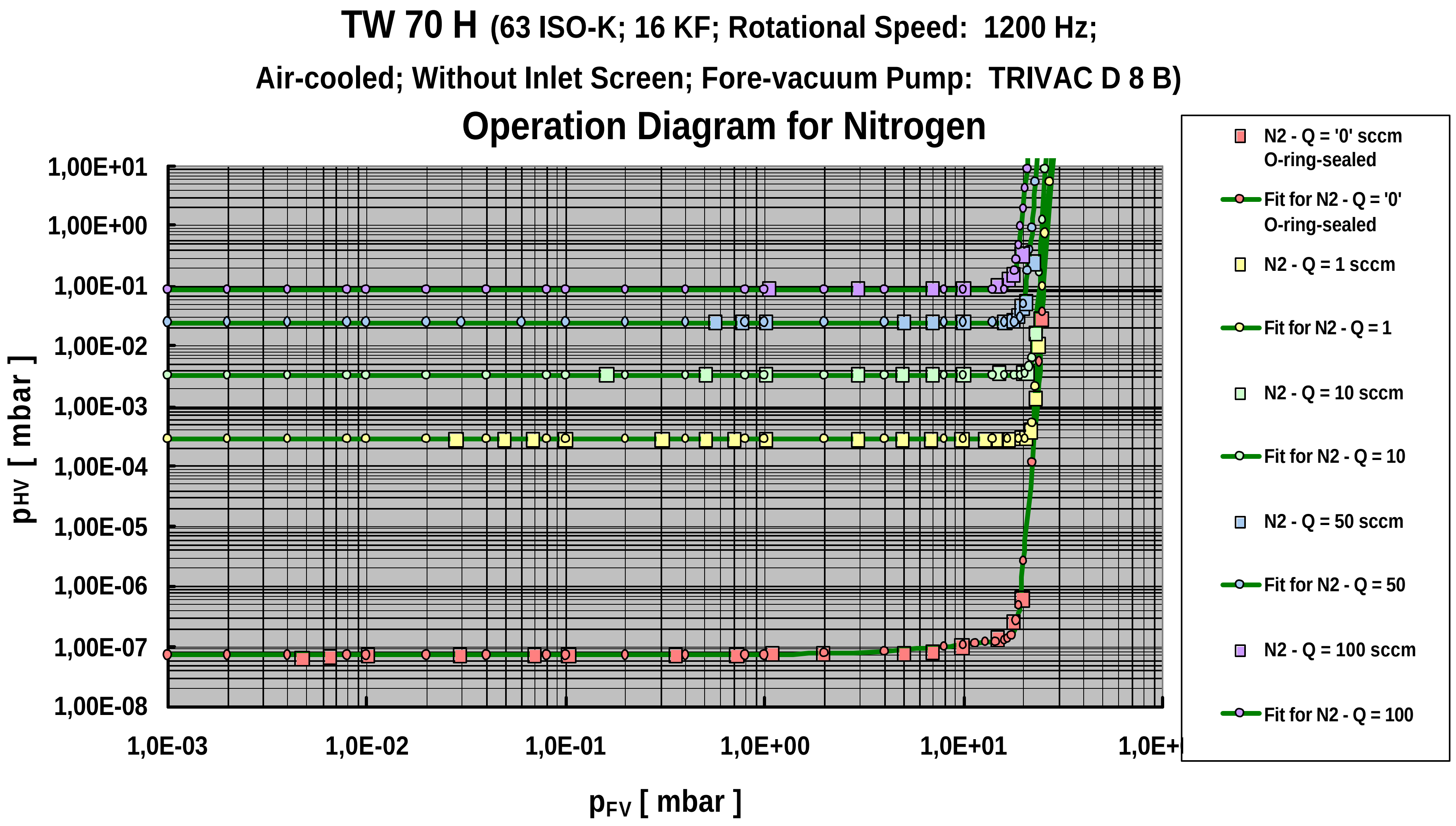
How to measure compression of turbomolecular pumps ?

How to analyse compression data ?

How to choose the right backing pump system ?

# Test Set-up for Determining the Compression of Turbomolecular Pumps





**TW 70 H** (63 ISO-K; 16 KF; Rotational Speed: 1200 Hz;

Air-cooled; Without Inlet Screen; Fore-vacuum Pump: TRIVAC D 8 B)

**Operation Diagram for Nitrogen**

# Graph of High-Vacuum Pressure as a Function of Backing Pressure

**“$p_{HV}$ versus $p_{FV}$”**

The heavy lines in Fig. 2 are graphical representations of fit functions for the individual measurement series.

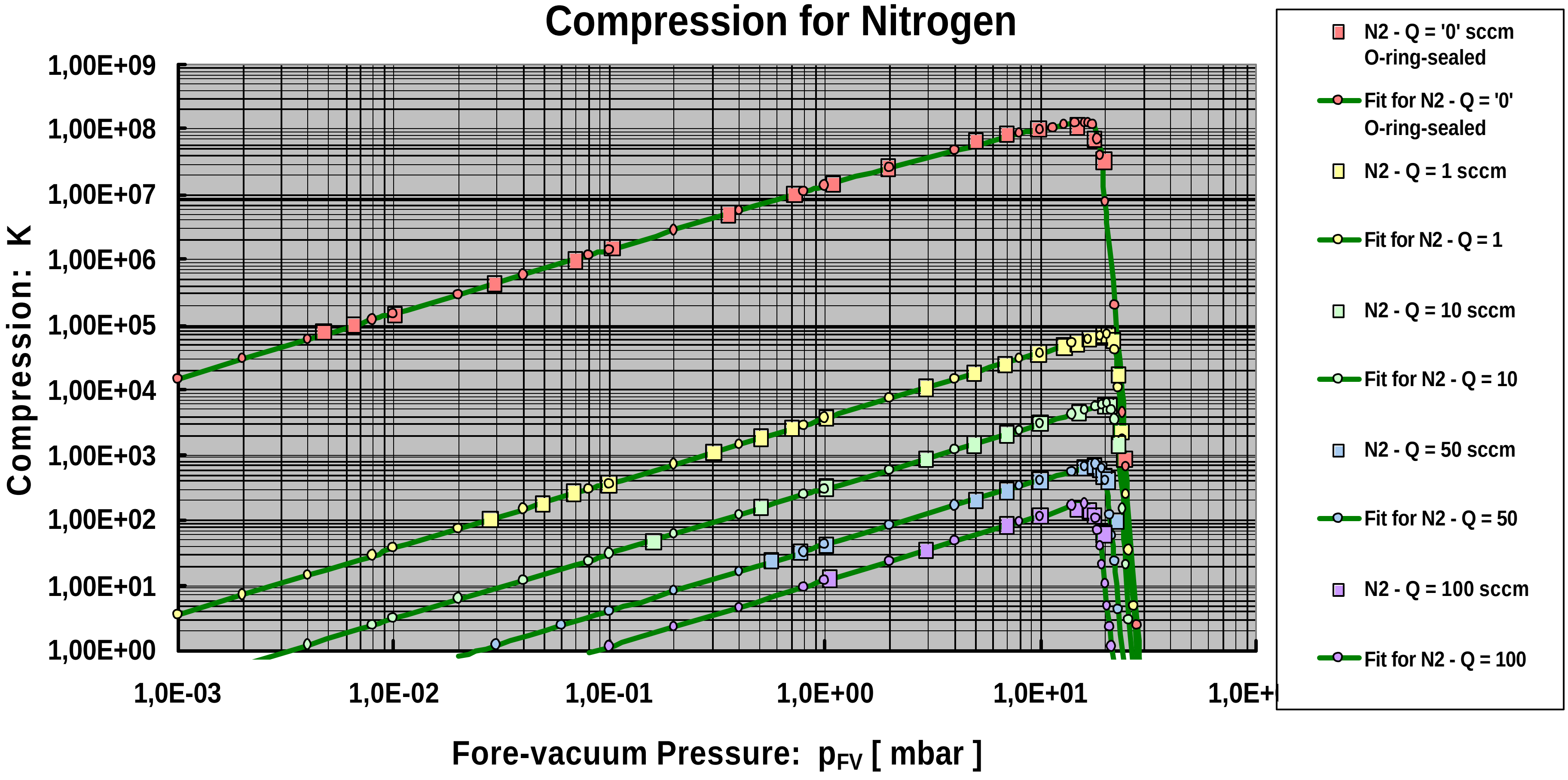
The fit function proposed by the author reads (*):

$$p_{HV} = p_{HV}(p_{FV}) = p_1 * [\exp(\beta * (p_{FV} - C_2)) + 1]$$

The fit parameters $p_1$, $\beta$ and $C_2$ depend on the prescribed gas throughput Q. $p_1$ is the lowest high-vacuum pressure that can be reached with the turbomolecular pump at the prescribed gas throughput Q.

(*): G. Voss, published in “Vakuum in Forschung und Praxis”, **14** (2002), No. 4, p. 228 f

# **TW 70 H** (63 ISO-K; 16 KF; Rotational Speed: 1200 Hz; Air-cooled; Without Inlet Screen; Fore-vacuum Pump: TRIVAC D 8 B)



# Graph of Compression

# as a Function of Backing Pressure

## “K versus $p_{FV}$”

The compression K of a turbomolecular pump is defined as the ratio of backing pressure to high-vacuum pressure: $K = K(p_{FV}) = p_{FV} / p_{HV}$ .

The heavy lines in Fig. 3 are graphical representations of fit functions for the individual measurement series.

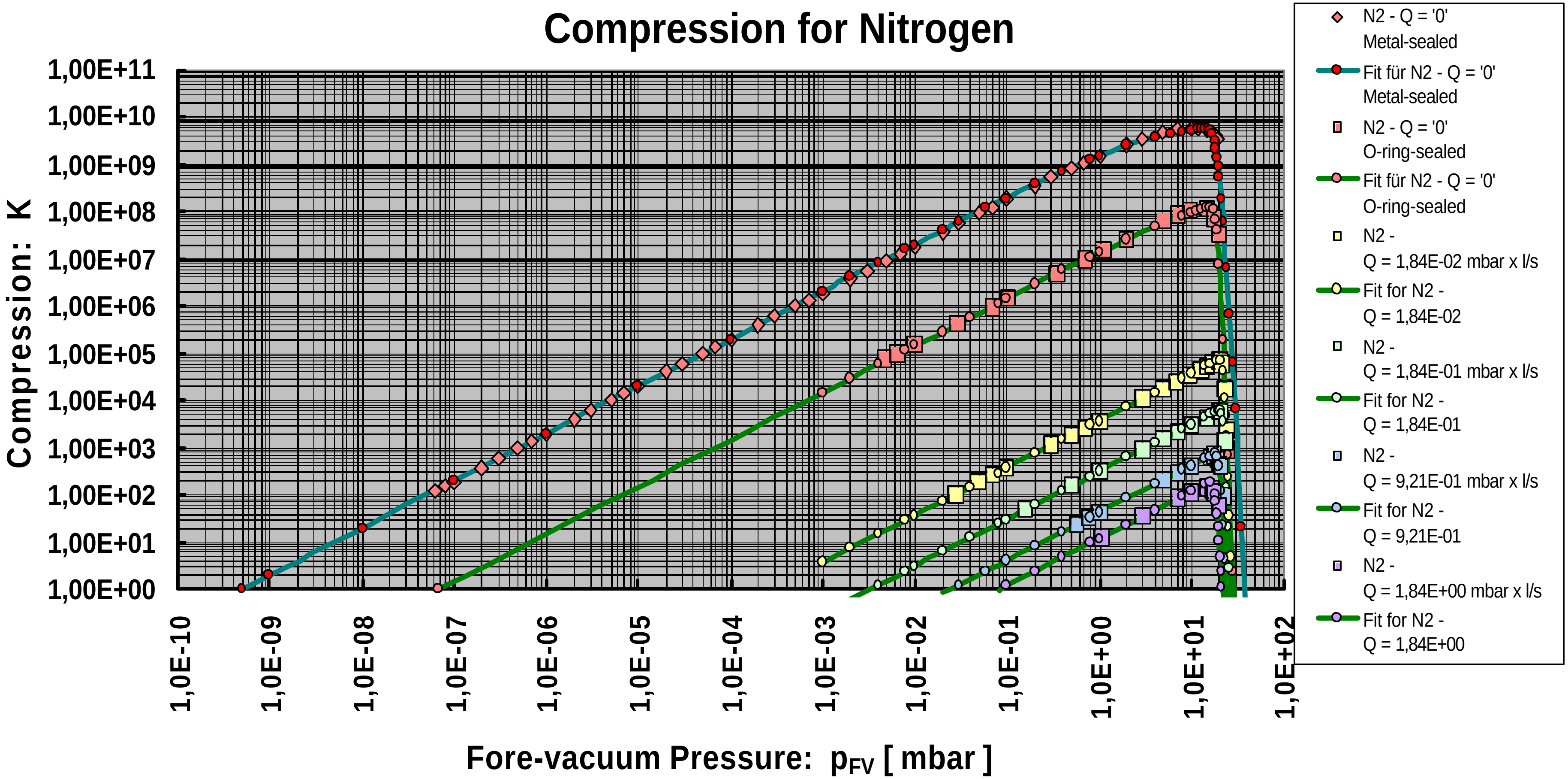
The fit function proposed by the author reads:

$$K(p_{FV}) = p_{FV} / p_{HV}(p_{FV}) = (p_{FV}/p_1) * [\,\exp(\beta*(p_{FV} - C_2)) + 1]^{-1}$$

Note that the compression of a turbomolecular pump increases, if the gas throughput Q is reduced at a prescribed backing pressure $p_{FV}$.

## **TW 70 H** (63 ISO-K; 16 KF; Rotational Speed: 1200 Hz; Air-cooled; Without Inlet Screen; Fore-vacuum Pump: TRIVAC D 8 B)

## Compression for Nitrogen



# Graph of Zero-Throughput Compression as a Function of Backing Pressure

**“$K_0$ versus $p_{FV}$”**

The zero-throughput compression $K_0$ of a turbomolecular pump is defined as the pump’s compression at “zero” gas throughput.

To fit the zero-throughput compression data successfully the fit function for $K(p_{FV})$ given above has to be modified.

Brand new: The fit function proposed by the author reads now:

$$K(p_{FV}) = p_{FV} / p_{HV}(p_{FV}) = [p_{FV} /(\mathbf{a*p_{FV}} + p_1)] * [\exp(\beta*(p_{FV} - C_2)) + 1]^{-1}$$

Note that the modification is necessary only in case of small gas throughputs, i.e. Q smaller than 1 sccm ≅ 2 x $10^{-2}$ mbar*l/s.

# Graph of Zero-Throughput Compression as a Function of Backing Pressure

**“$K_0$ versus $p_{FV}$”**

Note that two situations can occur:

1. **$a^*p_{FV}$** is small compared with $p_1$

   In this case $K_0$ is a linear function of backing pressure: $K_0 \propto p_{FV}$

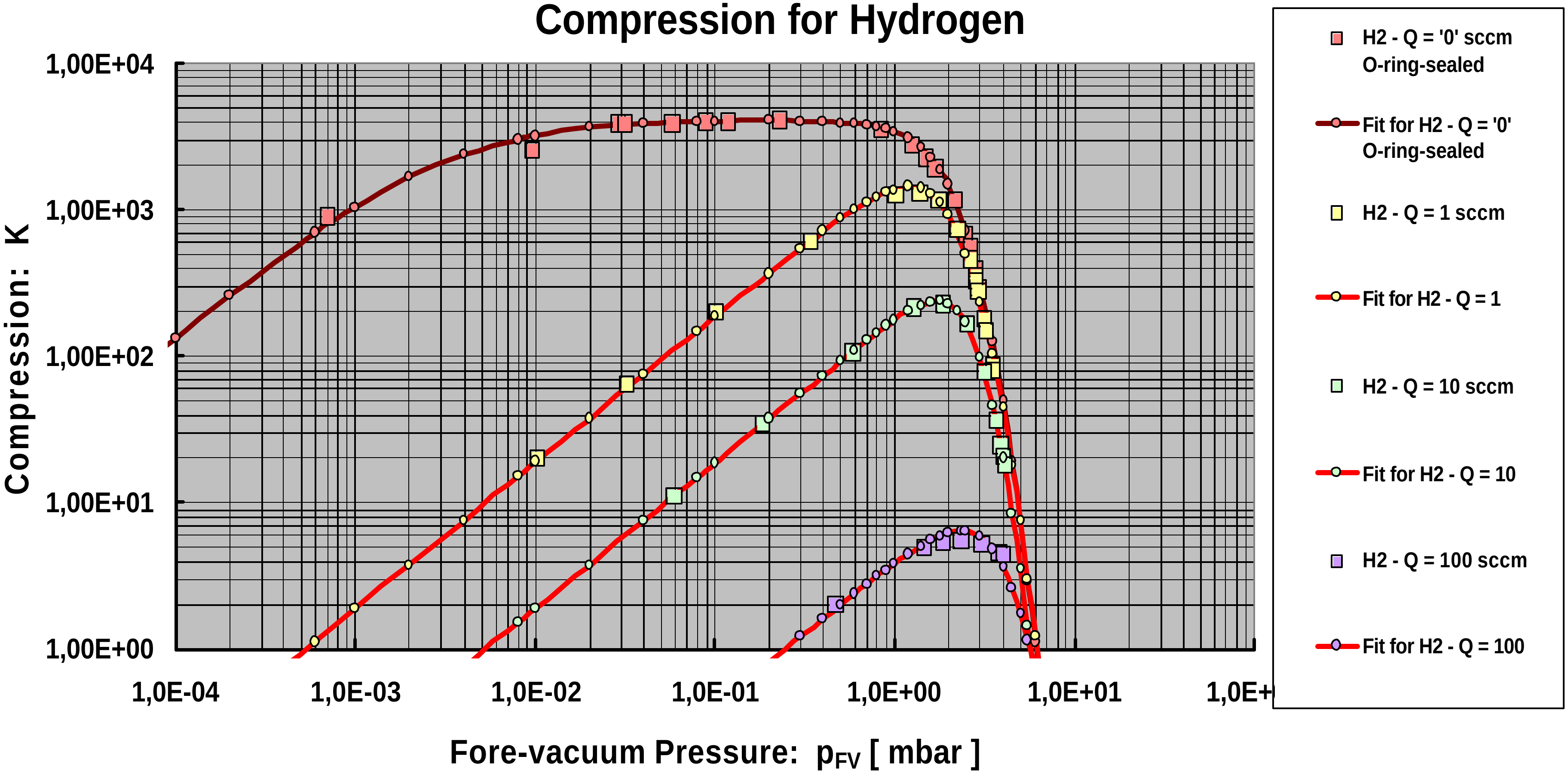
2. **$a^*p_{FV}$** is large compared with $p_1$

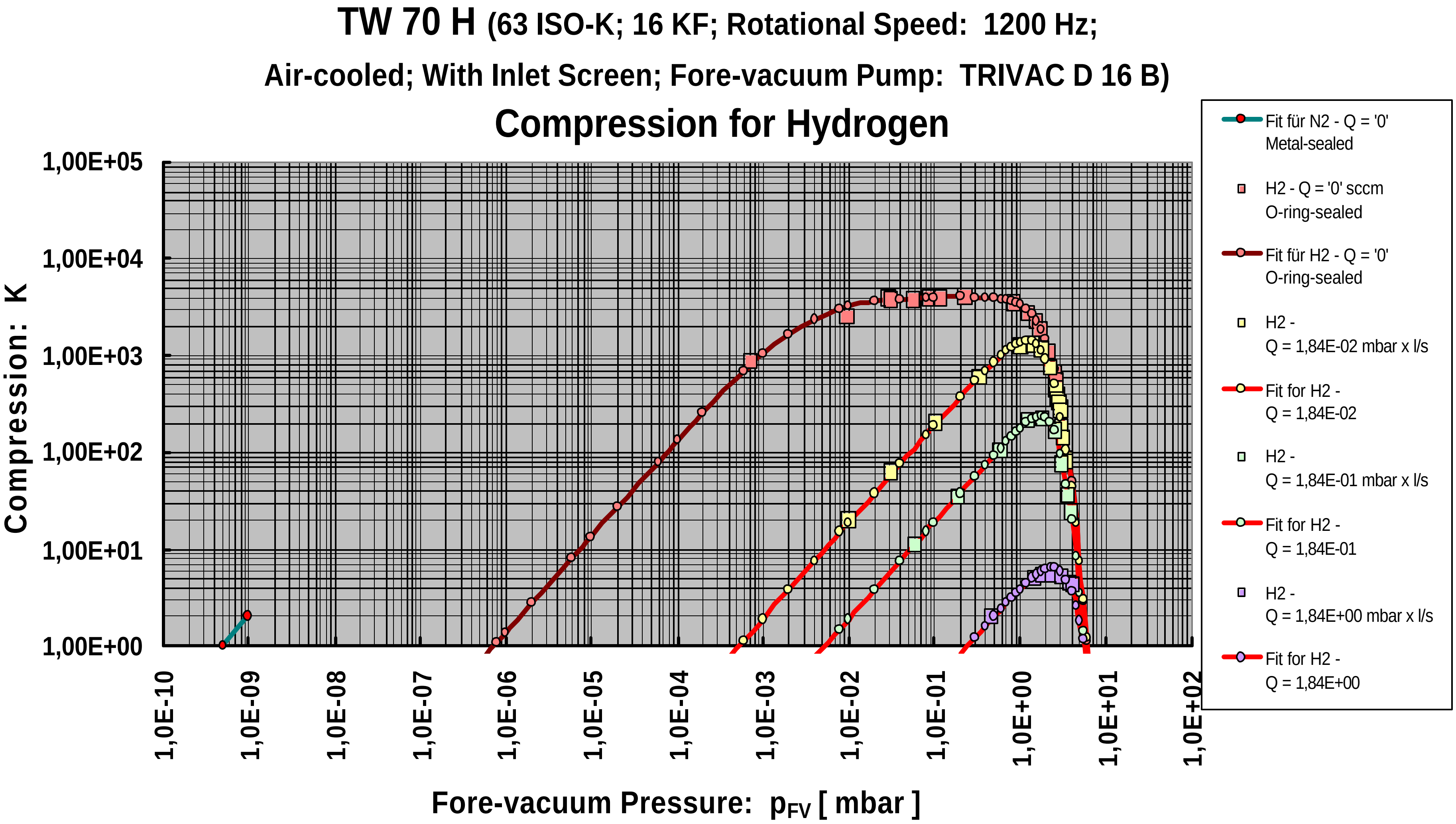
   In this case $K_0$ is a constant: $K_0 \approx 1/a$

$$K(p_{FV}) = p_{FV} / p_{HV}(p_{FV}) = [p_{FV} / (\mathbf{a^*p_{FV}} + p_1)] * [\exp(\beta^*(p_{FV} - C_2)) + 1]^{-1}$$

# **TW 70 H** (63 ISO-K; 16 KF; Rotational Speed: 1200 Hz; Air-cooled; With Inlet Screen; Fore-vacuum Pump: TRIVAC D 16 B)

## Compression for Hydrogen





**TW 70 H** (63 ISO-K; 16 KF; Rotational Speed: 1200 Hz;
Air-cooled; With Inlet Screen; Fore-vacuum Pump: TRIVAC D 16 B)

**Compression for Hydrogen**

# Choosing the right Backing Pump System
# for the Turbomolecular Pump

Key Message:

To achieve the lowest possible high-vacuum pressure $p_{HV}$ with the turbomolecular pump at a prescribed gas throughput the backing pump system must be able to generate such low backing pressures $p_{FV}$ that the compression K or $K_0$ is a linear function of backing pressure,
i.e. **$a*p_{FV}$** must be small compared with $p_1$ .

$$K(p_{FV}) = p_{FV} / p_{HV}(p_{FV}) = [p_{FV} /(\mathbf{a*p_{FV}} + p_1)] * [ \exp(\beta*(p_{FV} - C_2)) + 1]^{-1}$$

$$p_{HV} = p_{HV}(p_{FV}) = (\mathbf{a*p_{FV}} + p_1) * [ \exp(\beta*(p_{FV} - C_2)) + 1]$$

# Examples

TW 70 H; O-ring-sealed; Nitrogen; $K_0$:
$a = 3.5 \times 10^{-9}$, $p_1 = 6.9 \times 10^{-8}$ mbar, $\beta = 1.9$ mbar $^{-1}$, $C_2 = 18.5$ mbar
$\Rightarrow p_{FV}$ should be smaller than $p_1/(10*a) = 2$ mbar.

TW 70 H; Metal-sealed; Nitrogen; $K_0$:
$a = 1.4 \times 10^{-10}$, $p_1 = 5.0 \times 10^{-10}$ mbar, $\beta = 1.15$ mbar $^{-1}$, $C_2 = 18.0$ mbar
$\Rightarrow p_{FV}$ should be smaller than $p_1/(10*a) = 0.35$ mbar.

TW 70 H; O-ring-sealed; Hydrogen; $K_0$:
$a = 2.3 \times 10^{-4}$, $p_1 = 7.0 \times 10^{-7}$ mbar, $\beta = 1.9$ mbar $^{-1}$, $C_2 = 1.65$ mbar
$\Rightarrow p_{FV}$ should be smaller than $p_1/(10*a) = 3 \times 10^{-4}$ mbar.

# Summary

For the first time, an analytical function has been presented

- which excellently describes how the compression of turbomolecular pumps depends on backing pressure
- which can be used to fit compression data over the full backing pressure range
- which allows to choose the right backing pump system to achieve the lowest possible high-vacuum pressure.