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PUMPING CHARACTERISTICS OF ROOTS BLOWER PUMPS FOR LIGHT ELEMENT GASES

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Seiji HIROKI, Tetsuya ABE, Sadamitsu TANZAWA,
Jun-ichi NAKAMURA* and Tetsuro OHBAYASHI*

日本原子力研究所
Japan Atomic Energy Research Institute

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Pumping Characteristics of Roots Blower Pumps for Light Element Gases

Seiji HIROKI, Tetsuya ABE, Sadamitsu TANZAWA,
Jun-ichi NAKAMURA* and Tetsuro OHBAYASHI*

Department of Fusion Engineering Research
Naka Fusion Research Establishment
Japan Atomic Energy Research Institute
Naka-machi, Naka-gun, Ibaraki-ken

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The pumping speed and compression ratio of the two-stage roots blower pumping system were measured for light element gases (H_2, D_2 and He) and for N_2, in order to assess validity of the ITER torus roughing system as an ITER R&D task (T234). The pumping system of an Edwards EH1200 (nominal pumping speed of 1200 m^3/s), two EH250s (ibid. 250 m^3/s) and a backing pump (ibid. 100 m^3/s) in series connection was tested under PNEUROP standards. The maximum pumping speeds of the two-stage system for D_2 and N_2 were 1200 and 1300 m^3/h, respectively at 60 Hz, which satisfied the nominal pumping speed. These experimental data support the design validity of the ITER torus roughing system.

Keywords: Roots Blower Pump, Light Element Gas, Pumping Speed, Compression Ratio, PNEUROP Standard, ITER, Roughing Pump, Cryopump, Regeneration

*Osaka Vacuum Ltd.

ルーツ真空ポンプの軽元素ガスに対する排気特性

日本原子力研究所那珂研究所核融合工学部
廣木　成治・阿部　哲也・丹澤　貞光・中村　順一*・大林　哲郎*

(2002年　5月 15日受理)

ITER粗引システム設計の妥当性を評価するため、2段ルーツ真空ポンプシステムの軽元素ガス(軽水素H_2、重水素D_2、ヘリウムHe)及び窒素ガスN_2に対する排気特性（排気速度及び圧縮比）の試験をITER R&Dタスクとして実施した 。試験では、エドワーズ社ルーツ真空ポンプEH1200（1台、公称排気速度1200 m^3/s）と同EH250（2台、同250 m^3/s）及びロータリーポンプ（1台、同100 m^3/s）を直列に接続し、ヨーロッパ真空規格に準拠して実験を行った。そして、2段ルーツ真空ポンプシステムのD_2及びN_2に対する最大排気速度はそれぞれ、1200と1300 m^3/hであり、公称排気速度を満たすことを確認した。本試験結果は、2段ルーツ真空ポンプシステムからなるITER粗引システム設計の妥当性を裏付けるものである。

那珂研究所　〒311-0193　茨城県那珂郡那珂町向山801-1
*(株)大阪真空機器製作所

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1. Introduction

International Thermonuclear Experimental Reactor (ITER) has been designed to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. The technical main objective is to achieve extended burn in inductively-driven D-T (Deuterium-Tritium) plasma operation with $Q \geq 10$ (Q is the ratio of fusion power 0.5 GW to auxiliary power injected into the plasma), with an inductive burn duration of 300~500 sec[1]. To satisfy the mission, the ITER primary pumping system has been designed, which comprises the torus roughing system and the high vacuum system[2]. The torus roughing system comprises roots blower pumps backed by large tritium compatible piston pumps[3], and is used to evacuate the torus from an atmospheric pressure to the cross-over pressure (10 Pa) of cryopumps of the high vacuum system, and to regenerate the cryopumps.

The roots blower pump is widely used in various areas such as in semi-conductor industries for improving a pumping speed in a medium vacuum range, in conjunction with a coarse vacuum pump such as an oil rotary pump. However, there is no reliable data on pumping characteristics of D_2, due to its very expensive and explosive gas. D_2 is a part of the D-T fusion fuel gas, so experimental pumping data on D_2 are essential for design of the ITER torus roughing system. Hence, the pumping speeds and compression ratios of the roots blower pump system were measured for D_2, and for reference, hydrogen (H_2), helium (He) and nitrogen (N_2), as an ITER R&D task. This report describes the test procedures and results on the characterization of the roots blower pump.

2. Test Procedure

Figure 1 shows the ITER torus roughing system which comprises a first stage roots blower pump (nominal pumping speed of 4200 m^3/h at 50 Hz operation) and two second stage roots blower pumps (1200 m^3/h each), backed by two piston pumps (180 m^3/h each). The torus roughing system transfers the gas to the tritium plant via double contained piping. The test system shown in Fig. 2 can simulate the ITER torus roughing system, although it has only about a quarter of the pumping speed of the ITER system due to the cost saving. The test was implemented using an Edwards EH1200 (1200 m^3/h) for the first stage and two EH250s (250 m^3/h) for the second stage, and a 60 Hz AC power. Technical data quoted from the catalogue are shown in Table 1.

Table 1 Technical data on EH1200 and EH250.

Technical data	Unit	EH1200	EH250
Pumping speed	m^3/h	1200(50Hz) 1400(60Hz)	250(50Hz) 300(60Hz)
Motor rating	kW	3.0	1.5
Oil capacity	L	4.4	2.0
Cooling water flow	L/h	120	-
Mass	kg	149	61
Inlet connection	mm	ISO 160	ISO 63
Outlet connection	mm	ISO 100	ISO 40

All measurements were proceeded under PNEUROP standards[4]. The Baratron® was used for the pressure gauges of P1, P2 and P3. The test gases of H_2, D_2, He and N_2 were introduced into a test dome through a calibrated mass flow meter (MFM). The test dome was also manufactured under the PNEUROP standards. The gas throughputs into the test dome were approximately from 0.5 sccm (8.4×10^{-4} Pa·m^3/s) to 40 slm (67 Pa·m^3/s). A backing pump was the Osaka vacuum oil-sealed rotary pump, model P180 (180 m^3/h) of an anti-explosion type. A photograph of the test system is shown in Fig. 3.

An inlet pressure of the backing pump (P3) was controlled to trace the pumping speed curve shown in Fig. 4, which was determined by the experimental results of the piston pump[3]. The simulated maximum pumping speed of 100 m^3/h was planned to represent approximately a quarter of that of the gross two ITER piston pumps. For the pumping speed (S) measurement, the test gas with a projected flow rate (Q_g) was introduced into the dome and the inlet pressure (P) was measured, then the S is calculated to be $S=Q_g/P$. A conductance of the valve V3 (in Fig. 2) was regulated to trace the curve of Fig. 4. Besides for a compression ratio (K) measurement, a suitable amount of the test gas was introduced into the line through the variable leak valve V2 (in Fig. 2), together with controlling the conductance of the V3 to indicate the plotted pressures of Fig. 4, while there was a nil throughput of the test gas from the test dome. The K is then, calculated to be $K=P_b/P_{in}$, in which the P_b and P_{in} are defined as the backing pressure and the inlet pressure for each roots pump, respectively. The exhaust H_2 and D_2 from the backing pump were, in particular, diluted by N_2 of 1 slm (1.67 Pa·m^3/s) to prevent chemical explosions and bubbled into a water to cut off a back streaming of air. Each pressure reading was checked every 15 minutes and the latter of two successive readings within 5% of the former value was adopted for a valid value[4].

3. Results and Discussion

At first, a helium leak test was implemented to ensure a vacuum quality of the test system. Welded components such as the test dome and flanges were individually tested with the ANELVA helium leak detector (model-ASL-25V) and the results are shown in Table 2. An integrated leak test for the test system shown in Fig. 2 was then, implemented by using the pressure rise method. The leak rate Q_L can be written as;

$$Q_L = \Delta P_L \times Q / (\Delta P - \Delta P_L), \quad (1)$$

where ΔP_L and ΔP are pressure rises defined as follows;

ΔP_L: pressure rise in a pump under leak testing which has kept closed for 5 minutes after evacuated low enough with the oil-sealed rotary pump.

ΔP: pressure rise in the pump into which nitrogen gas has introduced for 5 minutes at the constant flow rate Q (5 sccm) after evacuated low enough with the oil-sealed rotary pump. Table 3 shows the results of the integrated leak test by the pressure rise method. The integrated leak rate for the test system excepting P180 was 4.9×10^{-5} $Pa \cdot m^3/s$, which is sufficient for the ITER use because the ITER roughing system will be contained in a evacuating grove box[2].

Table 2 Results of the component leak test.

Component	Measured helium leak rate ($Pa \cdot m^3/s$)
Test dome	$< 3.0 \times 10^{-10}$
Connecting pipes with welded parts	$< 3.0 \times 10^{-10}$
Gas lines with junctions	$< 1.5 \times 10^{-10}$
Flanges between the test system and vacuum gauges	$< 1.0 \times 10^{-12}$

Table 3 Results of the integrated leak test.

Item	Measured leak rate ($Pa \cdot m^3/s$)
P180	2.3×10^{-4}
Test system except for P180	4.9×10^{-5}

Figure 5 shows the pumping speed vs. inlet pressure curves for the 2-stage (EH1200+EH250x2) system and the EH250x2 system, although the test system of EH250 is, in principle, not consistent with the PNEUROP standard. The flat pumping speed curves of the 2-stage system for four test gases overlap from 3 to 200 Pa, whereas a little difference can be seen for the pumping speed curves of EH250x2 due to insufficient compression ratios of the simulated backing pump. Table 4 shows the maximum pumping speed (S_{max}), where the 2-stage system indicates S_{max} of 1200 and 1300 m^3/h for D_2 and N_2, respectively at 60 Hz operation. An ultimate pressure of the 2-stage system was 4.1×10^{-1} Pa for D_2.

Table 4 Maximum pumping speed (S_{max}).

System	S_{max} (m^3/h)			
	H_2	D_2	He	N_2
EH250x2	350	400	430	470
EH1200+EH250x2	1200	1200	1200	1300

Figures 6 and 7 indicate the compression ratio vs. backing pressure curves for different stages, from which the maximum compression ratios (K_{max}'s) are summarized in Table 5. The K_{max} of the two-stage system is enough as 280 even for H_2.

Table 5 Maximum compression ratio (K_{max}).

System	K_{max}			
	H_2	D_2	He	N_2
EH250x2	15	20	20	31
EH1200	24	25	24	34
EH1200+EH250x2	280	380	390	600

The validity of the pumping speed S curve of Fig. 5 was evaluated by using the K obtained. The inlet pressure P_{in} and S in a case of fully exhausting a gas can be expressed as follows[5];

$$P_{in} = \left(\frac{1}{K} + \frac{S_b}{S_d}\right) \cdot P_b, \qquad (2)$$

$$S = \frac{K \cdot S_d}{S_d + K \cdot S_b} \cdot S_b, \qquad (3)$$

where S_b is a pumping speed of the backing pump and S_d a nominal pumping speed. Equation (3) shows that the roots pump boosts a pumping speed of the backing pump S_b by a factor of $K \cdot S_d / (Sd + K \cdot S_b)$ in a working inlet pressure range. Using Eqs. (2) and (3), we can calculate the pumping speed curves. Figure 8 indicates the calculated pumping speed curves of the 2-stage system for D_2 and N_2, where S_d is 1400 m^3/s at 60 Hz, and the values of K, P_b and S_b are derived from Figs. 4 and 5. A good correlation can be seen between the calculated and experimental curves of the pumping speeds, also for D_2 and He.

Based on the results obtained, we can estimate the projected maximum pumping speed of 4200 m^3/h for the ITER torus roughing system (EH4200+EH1200x2+Piston pumpx2), for light element gases.

4. Conclusion

Compression ratios and pumping speeds of the 2-stage roots blower pumps (EH1200+EH250x2) were measured for light element gases (H_2, D_2, He) and for N_2, to simulate the design of the ITER torus roughing system. The test was proceeded under PNEUROP standards. The maximum pumping speeds of the 2-stage system (EH1200+EH250x2) for D_2 and N_2 were 1200 and 1300 m^3/h, respectively at 60 Hz, which satisfied the nominal pumping speed. These experimental data support the design validity of the ITER torus roughing system.

Acknowledgements

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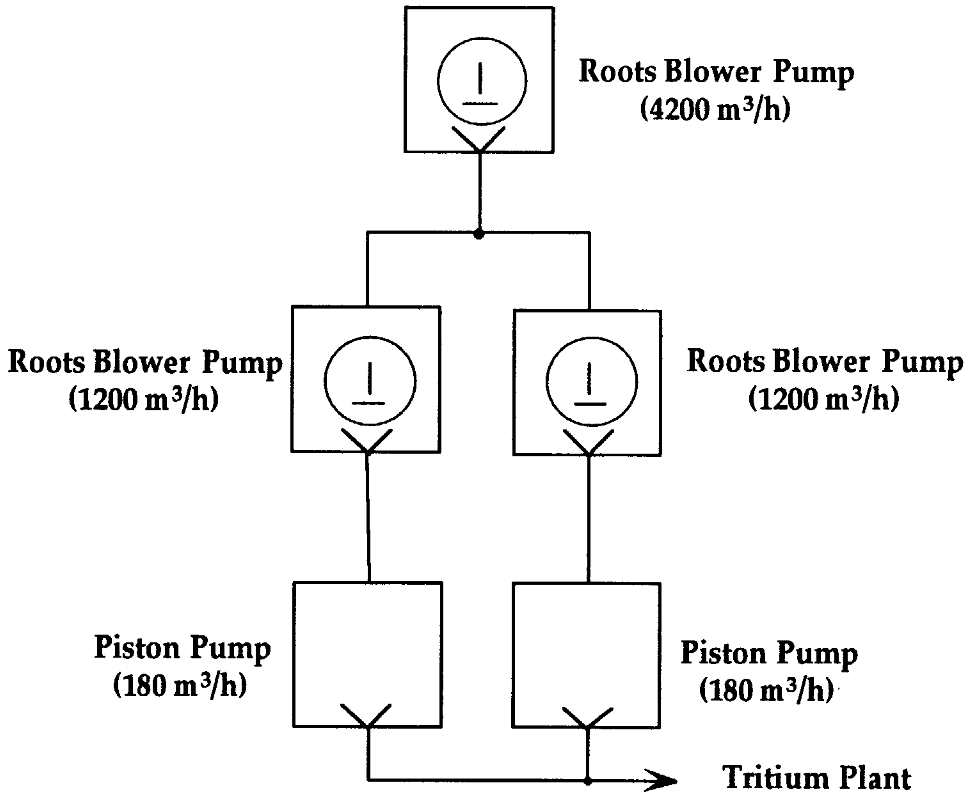

Fig. 1 ITER torus roughing system.

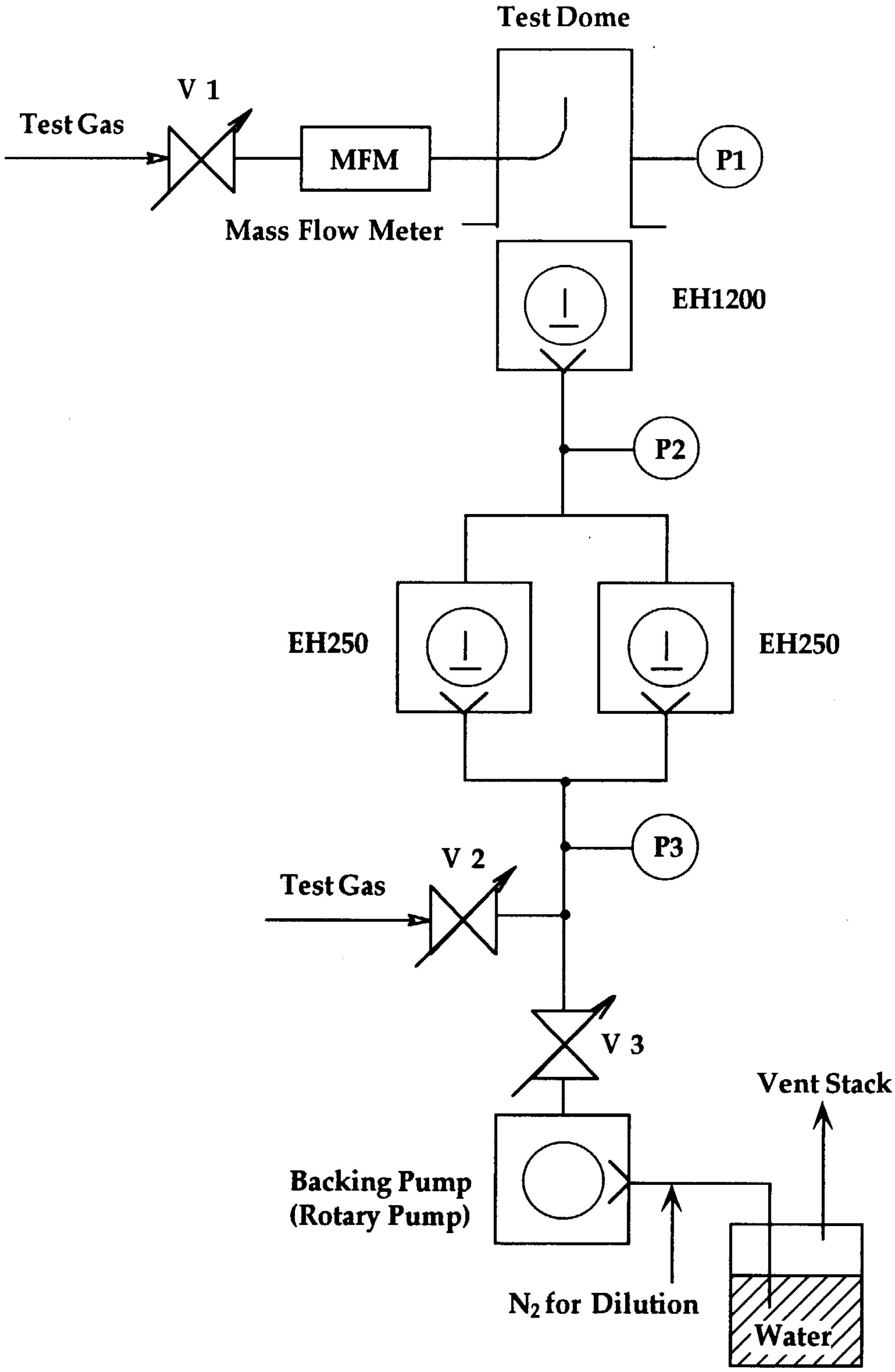

Fig. 2 Configuration of the test system.

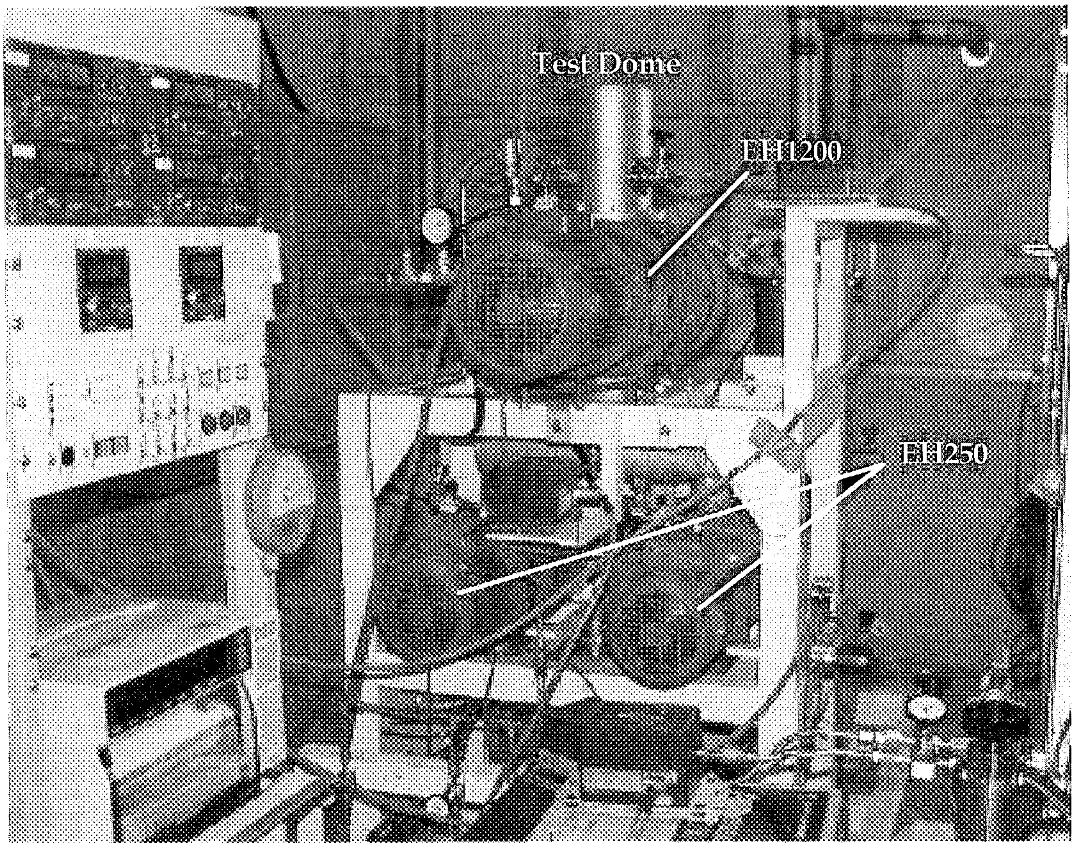

Fig. 3 Photograph of the test system.

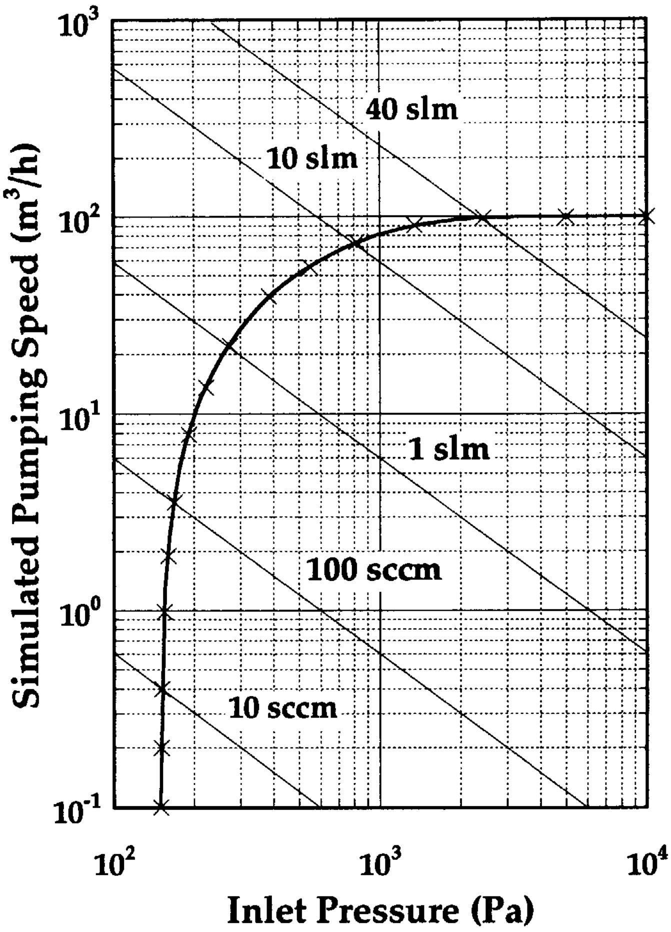

Fig. 4 Pumping speed vs. inlet pressure curve of the backing pump to be simulated.

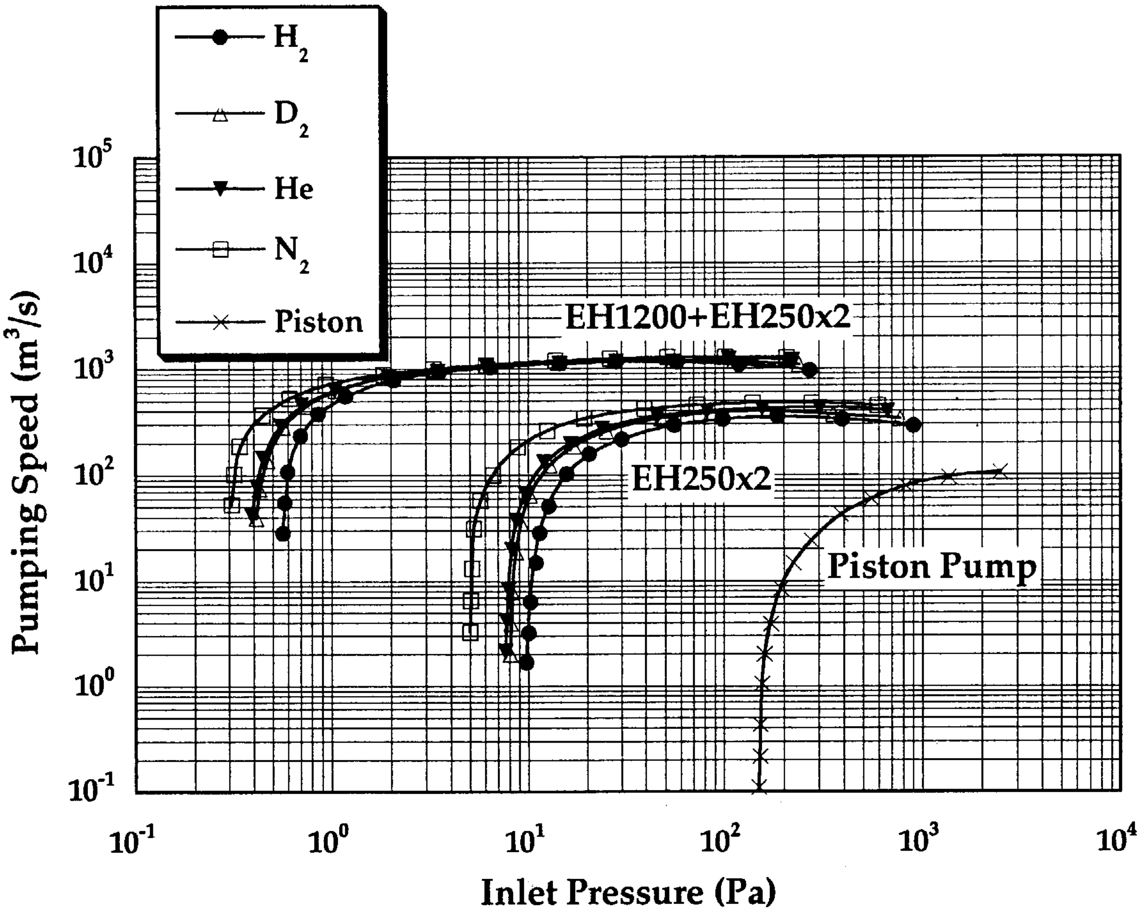

Fig. 5 Pumping speed vs. inlet pressure curves of 2-stage pumps and EH250x2.

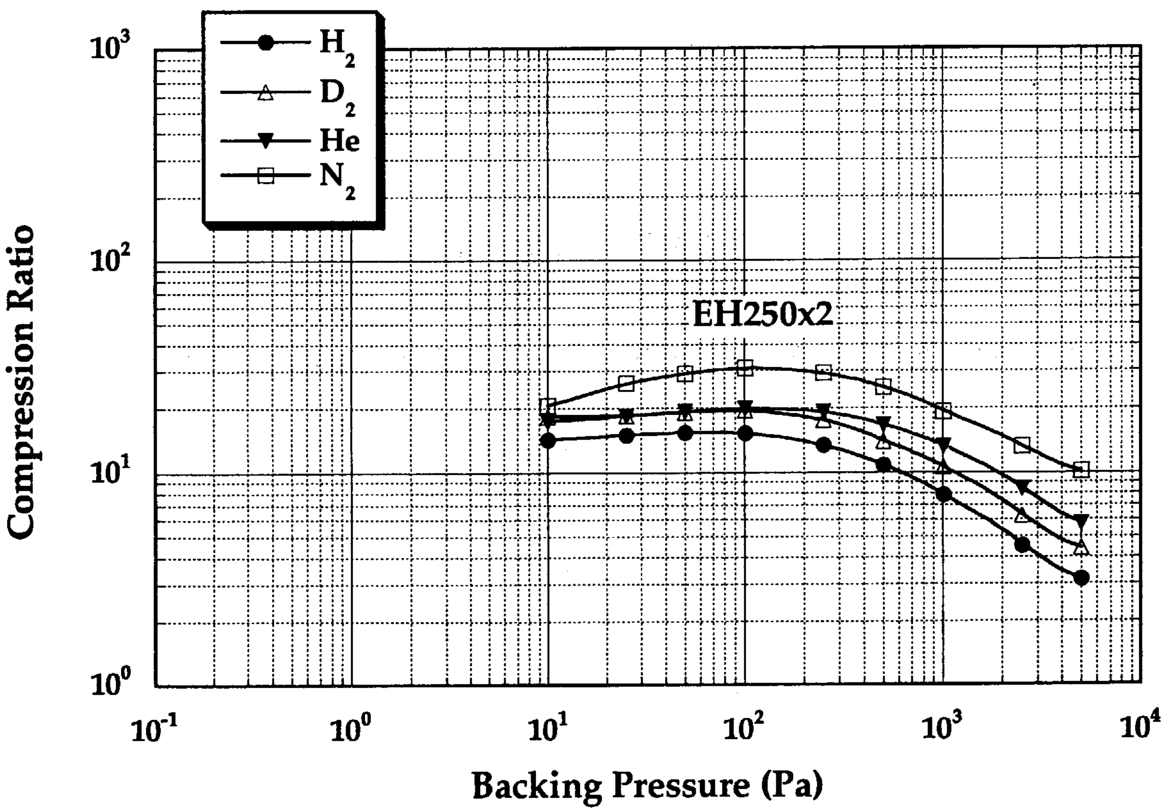

Fig. 6 Compression ratio vs. backing pressure curves of 2-stage roots blowers and EH1200.

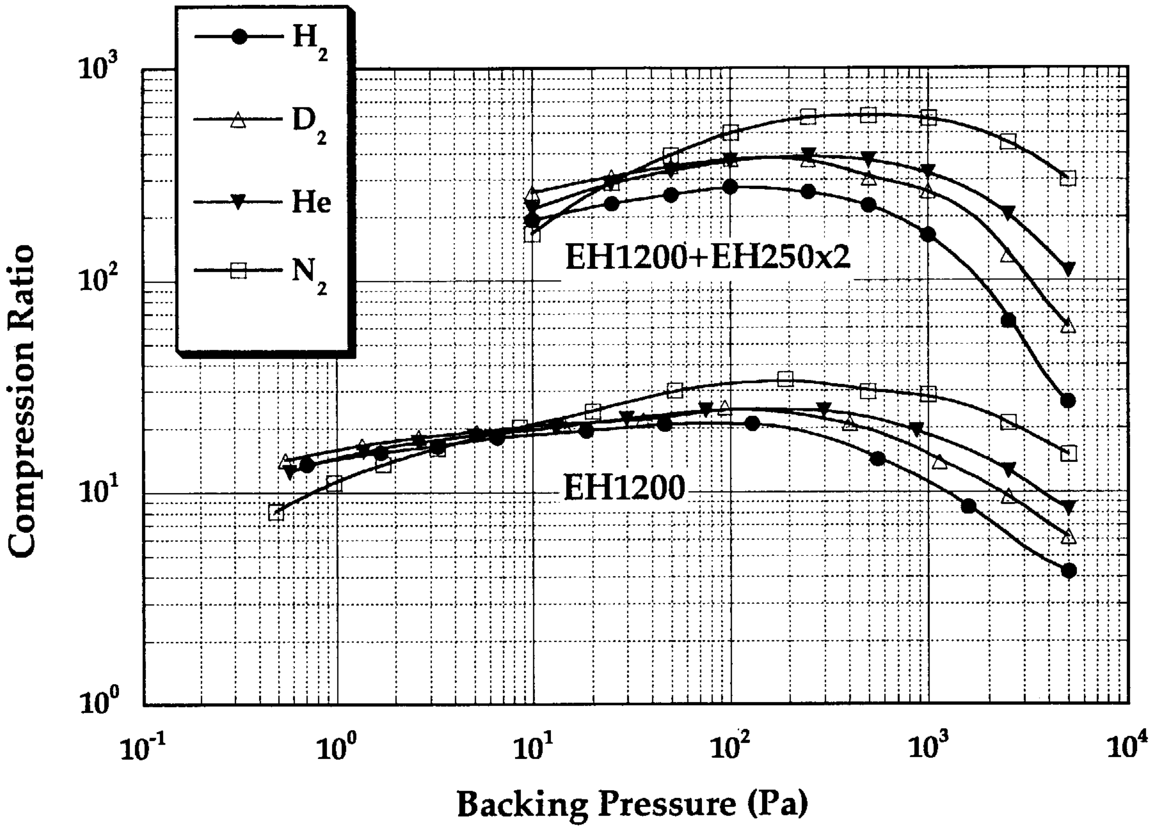

Fig. 7 Compression ratio vs. backing pressure curves of EH250x2.

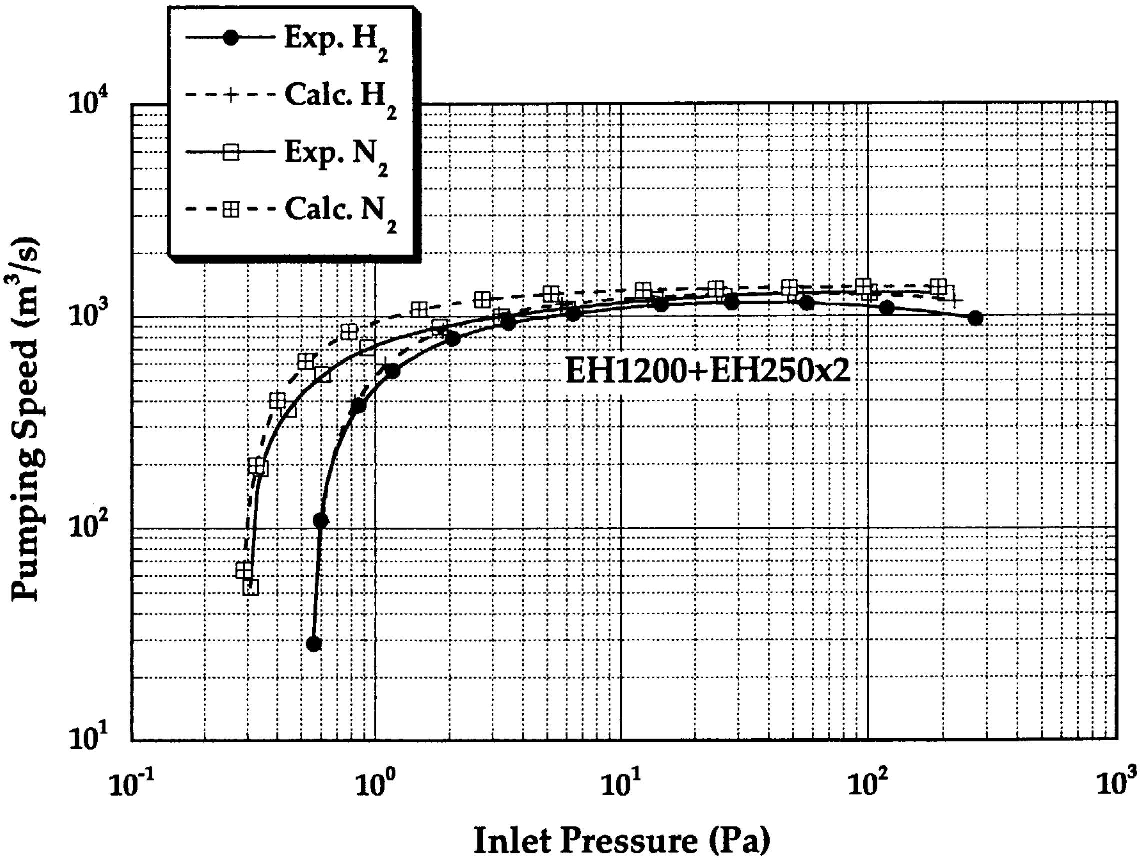

Fig. 8 Calculated pumping speed curves of 2-stage pumps for H_2 and N_2.

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国際単位系 (SI) と換算表

表1　SI基本単位および補助単位

量	名　称	記　号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表2　SIと併用される単位

名　称	記　号
分，時，日	min, h, d
度，分，秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV $=1.60218\times10^{-19}$ J

1 u $=1.66054\times10^{-27}$ kg

表5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m\cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	$N\cdot m$
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	$A\cdot s$
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	$V\cdot s$
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	$cd\cdot sr$
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å $=0.1$ nm $=10^{-10}$ m

1 b $=100$ fm$^2=10^{-28}$ m^2

1 bar $=0.1$ MPa $=10^5$ Pa

1 Gal $=1$ cm/s$^2=10^{-2}$ m/s^2

1 Ci $=3.7\times10^{10}$ Bq

1 R $=2.58\times10^{-4}$ C/kg

1 rad $=1$ cGy $=10^{-2}$ Gy

1 rem $=1$ cSv $=10^{-2}$ Sv

（注）

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eV および 1 u の値は CODATA の1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. bar は，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令では bar，barn および「血圧の単位」mmHg を表2のカテゴリーに入れている。

換　算　表

力	N($=10^5$dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　1 Pa·s(N·s/m^2) $=10$ P(ポアズ)(g/(cm·s))

動粘度　1 m^2/s $=10^4$St(ストークス)(cm^2/s)

圧力	MPa($=10$ bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J($=10^7$ erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal $=4.18605$ J (計量法)
$=4.184$ J (熱化学)
$=4.1855$ J (15 ℃)
$=4.1868$ J (国際蒸気表)

仕事率　1 PS (仏馬力)
$=75$ kgf·m/s
$=735.499$ W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

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Pumping Characteristics of Roots Blower Pumps for Light Element Gases

R100

古紙配合率100%
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