12.
5-30-95 JSD ①

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Various ATA Notes: 60, 79, 116, and 136

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ENGINEERING NOTE

SUBJECT

DIFFERENTIAL PUMPING STATION, ETA

NAME Clark Hanson

DATE February 15, 1979

The purpose of this note is to outline the reasons why it is important to develop and test a steam ejector for use on the differential pumping station.

The steam ejector (see attached figure) is mounted in the beam line (Stage I) and serves as a barrier between the air in Stage I and the 100 percent water vapor atmosphere in Stages II, III, and IV. The 100 percent water vapor atmosphere in these stages permit high volume pumping by super-cold surfaces.

To show the advantages of cryo-pumping water vapor over mechanical pumps/air, let us isolate Stage II and III and find out what vacuum equipment is required in each case.

A. One Hundred Percent Water Vapor and Cryopumping

Find Conductance of a 2 cm Diameter Orifice:

For viscous flow

where:

$$C = 20A \times \frac{\text{viscosity of air}}{\text{viscosity of steam}}$$

C = conductance, liters/second (l/s)

viscosity of air = .018 centipoise

viscosity of steam = approximately .010 centipoise

$$C = 20 \times \pi \times (1)^2 \times \frac{.018}{.010} = 113 \text{ l/s}$$

A = area of orifice, cm²

For two orifices in series

$$\frac{1}{C_T} = \frac{1}{C} + \frac{1}{C} = \frac{1}{113} + \frac{1}{113}$$

$$C_T = 57 \text{ l/s}$$

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Find Flow Rate thru Orifices:

$$Q = C_1(P_2 - P_3)$$

$$Q = 57(.15 - 1 \times 10^{-4})$$

$$Q = 8.55 \text{ torr-liters/second}$$

where:

Q = flow rate, torr-liters/second

C_T = conductance, l/s

P_2 = upstream pressure, torr

= .15 torr

P_3 = downstream pressure, torr
assume $P_3 = 1 \times 10^{-4}$ torr

Find Conductance of 12" I.D. Tube Between Chamber and LN₂ CooledSurface in TrapFor molecular flow

$$C_3 = 3.81 \sqrt{\frac{T}{M}} \frac{D^3}{L}$$

$$C_3 = 3.81 \sqrt{\frac{293}{18}} \times \frac{(30.5)^3}{35.6}$$

$$C_3 = 12,251 \text{ l/s}$$

where:

C = conductance, l/s

T = temperature of gas, °K
assume 293°K

M = molecular mass of molecule =
18 for H₂O

D = diameter in cm = 12" x 2.54 =
30.5 cm

L = length of tube, cm = 14" x 2.54 =
35.6 cm

Since the vacuum at the LN₂ cooled surface in the trap is $\leq 1 \times 10^{-6}$ torr because of the low vapor pressure of ice at LN₂ temperatures, the pumping speed of the system is equal to the conductance of the tube. Then, $S_3 = C_3 = 12,251 \text{ l/s}$.

Find Pressure in Stage III (Use two LN₂ traps)

$$P_3 = \frac{Q}{S_3} = \frac{8.55}{24,502}$$

$$P_3 = 3.5 \times 10^{-4} \text{ torr}$$

where:

Q = flow into chamber = 8.55 torr-liters/second

S_3 = pumping speed, l/s

= 2 x 12,251 l/s

= 24,502 l/s

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DIFFERENTIAL PUMPING STATION, ETA

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February 15, 1979

B. Air Atmosphere and Mechanical Pumps

Assume that the pressures in Stages II and III are the same as obtained with cryopumping and that the gas pumped is air rather than water vapor. How many Sargent Welch vertical turbopumps (1500 l/s pumping speed) would be required to attain 3.5×10^{-4} torr vacuum in Stage III?

"N" number of
Sargent Welch
Mod. 3133 vertical.
turbomolecular pump
1500 l/s pumping
speed, 6" inside
diameter

Find Conductance of 2 cm Orifice (Air)

$$C = 20A = 20 \times \pi \times (1)^2 = 63 \text{ l/s}$$

for two in series

$$C = \frac{63}{2} = 32 \text{ l/s}$$

Find Flow Rate into Stage III

$$Q = C \Delta P = 32(.15 - 3.5 \times 10^{-4}) = 4.8 \text{ torr-liter/second}$$

Find Conductance of Tube to Turbo Pump

$$C = 3.81 \sqrt{\frac{T}{M}} \frac{D^3}{L}$$

$$C = 6" = 15.2 \text{ cm}$$

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DIFFERENTIAL PUMPING STATION, ETA

NAME Clark Hanson

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$$C = 3.81 \sqrt{\frac{293}{29}} \frac{(15.2)^3}{15.2}$$

$$L = 6" = 15.2 \text{ cm}$$

$$M = 29 \text{ (air)}$$

$$C \approx 2,800 \text{ l/s}$$

$$T = 293^\circ \text{ K}$$

Find Overall Pumping Speed of 6" Tube and Turbo Pump (One Unit)

$$\frac{1}{S} = \frac{1}{S_p} + \frac{1}{C} = \frac{1}{1500} + \frac{1}{2800}$$

$$S = 977 \text{ l/s}$$

Find System Pumping Required to Maintain 3.5×10^{-4} Torr Pressure at a Gas Load of 4.8 Torr-Liter/Second

$$S_3 = \frac{Q}{P_3} = \frac{4.8}{3.5 \times 10^{-4}} = 13,714 \text{ l/s}$$

Find Number of Turbo Pumps Required to Produce Pumping Speed of 13,714 l/s

$$N = \frac{S_3}{S} = \frac{13,714}{977} = 14 \text{ turbomolecular vacuum pumps}$$

The above exercise in calculations dramatically illustrates the attractiveness of cryogenic pumping of 100 percent water vapor gas. Two ten-inch LN₂ traps will produce a vacuum which would require fourteen 1500 l/s turbo pumps, if air were pumped instead.

The proposed differential pumping system is based on the premise that no air will enter Stage II thru the 2 cm orifice connecting it to Stage I. Since air would pass at near sonic velocity from Stage I to II because of the pressure difference, some mechanism is required to reverse the direction of flow and replace air with 100 percent water vapor. The water vapor must also move at sonic velocity to prevent air from entering Stage II. An ejector using superheated steam (see attached figure) will perform this function very well.

Other advantages for using the steam ejector are:

1. The high temperature steam will mix with and heat incoming air, thus reducing air flow thru the 2 cm orifice.

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DIFFERENTIAL PUMPING STATION, ETA

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Clark Hanson

DATE

February 15, 1979

2. The momentum of the steam exhausting from the ejector will counter balance the momentum of air flow through the 2 cm orifice, thus reducing air flow into Stage I. The effects of one and two will reduce vacuum-pumping requirements for Stage I.
3. The steam ejector functions as a vacuum-pumping stage and removes gas from the tube adjacent to Stage II.

The above listed benefits make the use of a steam ejector very attractive. The next question to be answered is: Can we build a steam ejector which will function properly under our particular conditions? Terry Alger, Laser Isotope Program, LLL, was asked to evaluate the proposed design. Terry has had experience with supersonic wind-tunnel experiments as a graduate student at the University of Utah. His PhD. research dealt with two-phase nozzle flow studies. His evaluation of the ejector design and recommendations for its improvement are attached.

Conclusion

1. The cryogenic pumping of 100 percent water vapor is attractive because high-pumping speeds are obtained. With this system, it is possible to build a shorter (overall length) differential pumping station with larger-diameter beam orifices than with an air-atmosphere vacuum system.
2. It appears that an in-line steam ejector will function satisfactorily in our configuration and conditions, but will require testing to be certain. The results of these tests will also help finalize the design of the remaining stages.

Interdepartmental letterhead

Mail Station L-321

Ext: 2-27866

February 9, 1979

TO: C. L. Hanson

FROM: T. W. Alger

SUBJECT: Theoretical Evaluation of Nozzle/Diffuser Arrangement for Differential Pumping Unit

Upon investigating the nozzle/diffuser arrangement design proposed for the differential pumping unit, several conclusions and design recommendations concerning its performance can be made:

- 1) The optimally expanded exhaust pressure of the nozzle array, given the inlet condition of superheated steam at 5 psia and 600° F, will be near 0.2 psia (10 torr). This pressure will be determined by the nozzle throat and exhaust areas chosen for the final design.
- 2) The worst case for pressure recovery in the conical diffuser would be for a normal shock to occur at, or just downstream of, the nozzle exit. For this case, the fluid pressure would increase from 10 torr to 80 torr across the shock. However, this operating condition should be avoided since the normal shock would be located upstream of the area to be pumped and, therefore, would cause a pressure of 80 torr to be in a region where 10 torr is desired.
- 3) For the design geometry, the best pressure recovery would be obtained by locating a normal shock wave somewhere in the constant area channel following the conical diffuser. In this case, a pressure rise from 10 torr to near 160 torr would occur. However, to achieve this flow condition, the proper "starting" procedure must be incorporated. This involves starting the steam flow system with a sufficiently low back pressure (<80 torr) to move the normal shock wave out through the nozzle/diffuser assembly and into the constant area channel. Once the shock wave has moved through the system, the back pressure could theoretically be raised to the 160 torr. In practice, due to losses in the conveying diffuser, the full pressure rise to 160 torr will probably not be achieved. Also, the heat exchanger and noncondensable pumping units must be sized to account for the lower back pressure necessary to start the steam flow system.

Memo to C. L. Hanson
February 9, 1979
Page 2

- 4) For shockless flow throughout the complete nozzle/diffuser and constant area duct, the pressure at the duct exit would be near 100 torr. Thus, based upon this result and the results presented in sections 2) and 3), the desired pressure recovery from 10 torr to 100 torr seems quite reasonable.
- 5) The 15 degree converging diffuser half angle is rather high and may cause boundary layer separation and an associated, complex system of oblique shock waves to occur. This could result in a smaller pressure recovery than that defined earlier. In general, diffuser designs typically incorporate a near six-degree half angle to minimize the possibility of boundary layer separation and stagnation pressure loss. However, there is published data that indicates high efficiency diffusers have been demonstrated at 20-degree converging half angles. Thus, it is recommended that the converging half angle be made as small as possible within the other design constraints of the overall system.

T. M. Alger

vz 0798z

TWO STREAM INSTABILITY OF A BEAM IN THE
 DIFFERENTIALLY PUMPED TRANSPORT SECTION
 F.W. Chambers

Electron beams are stable to the two stream interaction at sufficiently low gas pressures such that the beam can not produce complete charge neutralization and at high pressures where beam temperature and plasma collisional effects suppress the instability. However, in a differentially pumped transport system the beam must pass through a range of pressures where it will be two-stream unstable. To prevent beam disruption, this region of instability must be sufficiently narrow to prevent the two stream mode from reaching large amplitudes. In this note we examine the maximum allowed width of the differential pumping section such that the two stream instability will not disrupt transport.

Two Stream Description

We describe the two stream interaction by the following dispersion relation:

$$D(\omega, k_{\parallel}, k_{\perp}) = 1.0 - \frac{\omega_{pe}^2}{\omega(\omega + i\nu)}$$

$$\frac{\omega_B^2 \left[\left(\frac{1}{\gamma^3} + \frac{I_{NET}}{I_A \gamma} \right) \frac{k_{\parallel}^2}{k^2} + \frac{1}{\gamma} \frac{k_{\perp}^2}{k^2} \right]}{\left(\omega - V_B k_{\parallel} + i k_{\parallel} \Delta V_{\parallel} + i k_{\perp} \Delta V_{\perp} \right)^2} \Bigg\} = \omega_B'^2$$

With:

$$V = 6.4 \cdot 10^9 \text{ p(torr)}$$

$$\omega_B^2 = \frac{4\pi n_B e^2}{m_e}, \quad \omega_{pe}^2 = \frac{4\pi n_p e^2}{m_e}$$

$$\frac{\Delta V_L^2}{C^2} = \frac{I_{NET}}{I_A}, \quad \frac{\Delta V_{||}}{C} = \frac{\Delta V_L^2}{2C^2} \quad I_A = 17050 \text{ } \gamma \text{ (AMPS)}$$

$$k_L = \frac{n_L \pi}{a} \quad n_L = 1/2 \text{ is the lowest mode}$$

$$k_{||} = \omega_{pe} / V_B \quad \text{usually assumed}$$

And with beam parameters:

$$I_B = I_{NET} = 10000 \text{ AMPS}$$

$$\gamma = 10 \quad \sim 5 \text{ MeV}$$

$$\tau_{PULSE} = 40 \text{ nsec.}$$

$$a = .5 \text{ cm}$$

The gas parameters when used are assumed to be:

$$\frac{dE}{dx} = 2.52 \frac{\text{MeV cm}^2}{\text{gm}}$$

$$\rho = 1.7 \cdot 10^{-6} \frac{\text{gm}}{\text{cm}^3} \times p(\text{torr})$$

$$\Delta E = 33.75 \text{ eV} / \text{ion pair}$$

Maximum Growth Rate

To compute the two stream growthrate for any p , n_e we need merely solve the polynomial DR numerically to obtain the growthrate as seen in figure 1. For $p = 0$ we can also use the approximate analytical solution:

$$\omega_i = \frac{\sqrt{3}}{2} \left(\frac{\omega_B'^2 \omega_{pe}}{2} \right)^{1/3} - K_{||} \Delta V_{||} - K_{\perp} \Delta V_{\perp}$$

The maximum observed growthrate at $n_e \approx 3.0 \cdot 10^{12}$ is $\omega_i = 7.6 \cdot 10^9$ corresponding to an e-folding length of 4 cm. Assuming we can tolerate a growth of 5 e-foldings this means the extent of the unstable region must be less than 20 cm.

Extent of the Unstable Region

The instability can not occur at pressures below that required for charge neutralization. For our assumed beam and gas parameters this pressure is $\approx .01$ torr. The maximum pressure for instability is ~ 5 torr so one concludes the differential pumping must drop the pressure from 5 torr to .01 torr in 20 cm. If the pressure drop is assumed linear then the transition from $\sim 0 \rightarrow 760$ torr could take place in 30 m. However, assuming a more realistic density profile; namely $p \sim p_0 e^{z/L_p}$, we find the distance L_p over which the pressure must drop by $1/e$ is $L_p = 3.22$ cm. The drop from $p = 5.0$ torr to $p = .01$ torr would have to take place over 20 cm. This would place a severe constraint on the pumping system. However, this calculation greatly overestimates the severity of the constraint imposed by the twostream because it assumes that the instability can grow at the maximum computed growthrate for the entire range of unstable pressures.

To better calculate the extent of the unstable region we should consider the instability at a fixed $k_{||}$ (and not at $k_{||} = \omega_{pe}/v_B$ where ω_{pe} varies with n_e). Essentially the plasma density will sweep through a range of values where a given $k_{||}$ mode will be unstable.

For a given $k_{||}$ the varying plasma density will sweep through the resonant region at $k_{||} = \omega_{pe}/v_B$. We assume that when the density has changed by a factor of e the instability shuts off. Thus the requirement for significant two stream growth is that the instability e-fold five times in the length that the density e-folds once, $L_p = 20$ cm. One could go from $p = 5.0$ to $p = .01$ torr in 1.25 m. This estimate is much more realistic than that of the previous paragraph.

Comments:

In doing the aforementioned approximations for the pulse response we have assumed the instability moves with the beam and the spatial instability is characterized by the exponentiation length

$\lambda_e = c/\omega_i$. Since for the weak two stream interaction $v_g = \partial\omega/\partial k = 2/3 v_B$ the first assumption is adequate. The second assumption is that the two stream mode is convective, this assumption is weaker since a slowly growing temporal mode could still reach large amplitudes during the pulse time. To completely justify the assumptions made would require a detailed inhomogeneous pulse response calculation.

Results are presented here for ETA; however, as seen in figure 2 the growth rates and hence exponentiation lengths are quite similar for ATA.

These approximate calculations are very conservative; a more detailed analysis, if warranted, would lead to somewhat less stringent constraints on the pumping system.

Growthrate Contours in N_e, p ETA parameters

-5-

DEPOLY

TIME = 09:54:07
DATE = 07/03/79

WZ=0.0 1.000E+00
N0.000E-01
I RHP= 1.000E+04
A C1 = 5.000E-01
GAP=0.0 1.000E+01
PTOR= 1.000E+01
LOG N= 1.800E+01
I RHP= 1.000E+04
APL= 0.

CC 1= 0.
CC 2= 1.526E+09
CC 3= 3.052E+09
CC 4= 4.578E+09
CC 5= 6.105E+09
CC 6= 7.631E+09
REDO= 7.631E+09

maximum
growth
 $\omega_i = 7.63 \cdot 10^9 / \text{sec}$

THE ETR 2-D WARM LORENTZIAN

figure 1

Growthrate Contours in N_e, p ATA parameters

-6-

DEPOLY

TIME = 10:04:49
DATE = 07/03/79

WZ/A = 1.000E+00
NCHD = 5.000E-01
I AMP = 1.000E+04
A CH = 5.000E-01
GROW = 1.000E+02
PTOR = 1.000E+01
LOG N = 1.000E+01
I NET = 1.000E+04
AFID = 0.

CC 1) = 0.
CC 2) = 1.164E+03
CC 3) = 2.227E+09
CC 4) = 3.491E+03
CC 5) = 9.034E+03
CC 6) = 5.702E+03
PRTOR = 5.318E+03

maximum
growth
 $\omega_i = 5.82 \cdot 10^9$

FIG. 519. 2-D WKB LORENTZIAN

p (torr)

figure 2

Reginato

Steam Ejector Prototype Unit Stage I

Differential Vacuum Pumping Station

C.L. Hanson

The steam ejector prototype unit (Stage I) has been successfully operated with a 2 cm diameter aperture opened to the atmosphere. A 10 torr vacuum was obtained on the suction side of the ejector during this test.

Stage I is one of four stages of the differential pumping station (Fig. 1) which will be connected to the end of the accelerator to provide an unobstructed passage from a high vacuum (5×10^{-6} torr) to the atmosphere. The accelerator beam will be focused through a series of 2 cm (.79") diameter openings without the use of foil windows. To remove the gas load from the adjacent higher pressure region, a vacuum pumping stage will be mounted between the 2 cm diameter openings.

The differential pumping stages consist of:

- 1) A superheated steam ejector, condenser and mechanical vacuum pump.
- 2) A freon-cooled trap and mechanical vacuum pump.
- 3) LN_2 traps and oil diffusion vacuum pumps.
- 4) Cryogenic vacuum pumps.

The flow of atmospheric air into the first stage is reduced by the injection of superheated steam into the air stream. Vacuum in the first state is produced by a steam condenser which remove the water vapor and a liquid ring mechanical vacuum pump which removes the air. A steam ejector has been built into the beam line to block off air flow into Stage II and produce a lower vacuum.

The water vapor in the second stage is removed by a freon cooled trap

operating at -50°C . This trap is connected to a roots blower and mechanical vacuum pump to remove the noncondensable gases.

The third stage consists of LN_2 traps and diffusion vacuum pumps to remove water vapor and residual non-condensable gases. Stage IV consists of a pair of cryogenic type vacuum pumps with high water vapor pumping capacity. The vacuum in the fourth stage will be equal or higher than that in the accelerator beam tube.

The flow schematic of the Stage I prototype test unit is shown in Fig. 2. 315°C (600°F) superheated steam is supplied to the ejector nozzles (5 total) and to a mixing station in the beam line on the atmospheric side. The steam ejector is supplied with 150 lbs/hr. of superheated steam at 550 torr pressure and develops a vacuum of 10 torr. The quantity of atmospheric air entering the condenser is reduced from 120 scfm to 15 scfm by mixing with 200 lbs/hr. of superheated steam. The steam is condensed by a direct cooling spray system and 70 sq. ft. of cooling plate surface. The air is removed by mechanical vacuum pumps (500 cfm pumping speed). The pressure in the condenser during the test was 60 torr.

Since the test of the Stage I prototype has been successful, design and procurement of parts for the remaining three stages can proceed as the program plan permits. Stage I is essentially complete and ready for mounting on a support structure yet to be designed for the differential pumping station.

DIFFERENTIAL PUMPING STATION
TOP VIEW

ATA Differential Pump
Survey of Pumping Methods

PURPOSE:

The purpose of this note is to present the results of a survey done to find the commercially available equipment to meet differential pump requirements for the Advanced Test Accelerator.

SCOPE:

Differential Pumping Unit requirements, for the Advanced Test Accelerator, are set forth as its ability to remove the air or any other selected gas that enters into the accelerator beam tube through a 2 cm diameter aperture. The differential pumping unit should maintain 2×10^{-6} torr base pressure in the beam tube. The maximum pressure differential across the 2 cm diameter aperture can be from 760 torr to 2×10^{-6} torr.

Conductance of an orifice (c) = $20 A \ell/\text{sc}$. (high pressure region)

where A = orifice area in cm^2

$$A = \pi 2^2/4 = 3.14 \text{ cm}^2$$

$$C = 20 \times 3.14 = 62.8 \ell/\text{sec}$$

$$= 62.8 \times 60/28 = 134.57 \text{ CFM}$$

$$= 134.57 \times 0.079 \times 60$$

$$= 605 \text{ lb/hr.}$$

$$C = 11.7 \times A \ell/\text{sec}$$

(low pressure region)

The equipment will be sized to handle the theoretical gas load of 135 SCFM leaking into the differential pumping unit.

To meet the basic requirements of the ATA differential pump one can divide the differential pumping system into a finite number of pumping stages. The actual number of the stages required to meet the system requirement will depend on the type of equipment used.

Figure No. 1 shows a differential pump divided into six stages. There is a 2 cm diameter orifice between each stage. Please note that beam focusing and steering magnets are installed inside the vacuum environment. The installation of the steering magnets inside the vacuum tank will require a smaller diameter magnet compared with installing the magnet on the outside. This will be cost effective.

Table #1 presents the vacuum calculations for the six stage differential pump shown in Figure #1.

FIGURE # 1
FIVE STAGE DIFFERENTIAL PUMP

Stage	0	1	2	3	4	5	6
Q-Torr-CFM	-	102,600	10260	945	67.5	2.2	0.02
P-Torr	760	76	7	0.5	2×10^{-2}	2×10^{-4}	2×10^{-6}
C-CFM	-	135	135	135	135	79	79
S-CFM	-	1350	1466	1890	3375	7900	7900

TABLE #1
VACUUM CALCULATIONS FOR A FIVE STAGE DIFFERENTIAL PUMP

where:

$$Q = C \times P_i \quad \text{TCFM}$$

$$C = 20 \text{ A } \ell/\text{sec} \quad \text{high pressure region}$$

$$C = 11.7 \text{ A } \ell/\text{sec} \quad \text{low pressure region}$$

$$P_i = \text{inlet pressure} - \text{torr}$$

$$P = \text{stage pressure} - \text{torr}$$

$$S = \text{pumping speed required at the stage to maintain stage pressure}$$

$$= C \times P_i / P$$

The pressure profile through the differential pump is shown in Figure No. 2. An extensive vacuum pump manufacture literature study was under taken to locate the vacuum pumps to do the job by using conventional vacuum pumps available from the vacuum pump manufacturers. To provide sufficient pumping speed at each stage to maintain the stage pressure as shown in Table No. 1. My study showed that vacuum pumps are available, with six to eight month delivery, that have the required through put to accomplish the task on hand.

I contacted a large number of vacuum pump manufacturers and narrowed my selection to three. The reason being that these three manufacturers made the pumps that are genetically different. In my judgement these manufacturers represent a good cross section of the vacuum pump industry.

I. Steam Jet Ejector

Figure #3 shows the use of steam ejectors for the high pressure stages. To pump down a 2 cm diameter aperture from 760 torr to 0.1 torr will require 2500 lb/hr steam, and 500 GPM of cooling water for the intercoolers. The estimated cost for a boiler, five ejectors with intercoolers is about \$300,000.

The steam ejectors are not very efficient below 0.1 torr base pressure. Therefore, this scheme will require diffusion pumps or some other means for the lower pressure stages at additional cost.

The steam boiler and ejector package is available from Kinema Inc. and others.

II. Combination of Liquid Ring Pumps, Mechanical Boosters and Diffusion Pumps

The system using this combination is shown in Figure #4. The pumps alone for this scheme will cost about \$175,000. There will be additional expenses for plumbing, instrumentation, interlocks and installation. These pumps can be purchased from Kinney Vacuum Co. and others.

III. Combination of Roots Pumps, Turbomolecular Pumps and Cryopumps

Figure #5 shows the combination of the above pumps. One should use combination of roots pumps for high pressure stage. The turbomolecular pumps and cryopumps should be used for lower press stages. Leybold-Heraeus among others manufacture roots pumping with pumping speeds up to 9000 CFM. A few inspections of these pumps, and some input from the users, gave me the assurance that these are high quality and very reliable machines. The estimable cost for the pumps for the scheme is about \$175,000.

Conclusion

After studying the various options, I would recommend the third scheme. The use of roots pumps combined with turbo and cryopumps. The required sizes of the pumps to do the job are available. This scheme will provide us with a dependable, clean and less complicated system to do the job.

0562p/prw

76

1ST STAGE.

DATE 12-3-80

10⁺¹

MODEL

2ND STAGE

10

1000000

3RD STAGE10⁻¹

100000

4TH STAGE10⁻²

10000

10⁻³

1000

10⁻⁴

100

10⁻⁵

10

10⁻⁶

PRESS. TORR.

LENGTH - FEET.

6TH STAGEPRESSURE PROFILE
THROUGH THE DIFF.
PUMPING SYSTEM

2

4

6

8

10

12

FIGURE 1A 2

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FIGURE NO. 4.

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FIGURE NO. 5