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EUROPEAN TRIP REPORT

April 29 through May 11, 1960

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This report covers a trip made to Europe by A. L. Eldredge and J. A. Pope under the auspices of the U. S. Atomic Energy Commission during the period of April 29 through May 11, 1960. The principal purpose of this trip was to evaluate European and English electroforming techniques. More specifically, the Electron Synchrotron (DESY) being constructed at Hamburg, Germany, uses linear accelerator sections as segments of the interaction structure in the Synchrotron. The present DESY intention is to electroform the disk-loaded waveguide for the accelerator sections in the Electron Synchrotron, following the basic principles of Stanford's electroforming approach.

The responsible investigators for DESY have found a vendor who produces high-purity, oxygen-free, high-conductivity copper with an efficiency that appeared to be twice as good as Stanford's electroforming efficiency; i.e., effective deposition rate is twice Stanford's. Accordingly, the purpose of this visit was to see the DESY project and the possible vendors of high-purity OFHC copper. We visited the Elmore's Metall-Aktiengesellschaft, located at Schladern/Sieg., Germany.

Several other firms were visited because their activity is technologicaly related to Stanford's work. These firms included: the Arthur Pfeiffer Company at Wetzlar, Germany; C.S.F. at Paris, France; English Electric Valve Company at Chalmsford, England; and Vickers Research at Sunninghill, England.

ELECTRON SYNCHROTRON (DESY)

The DESY project was described at the International Conference on High Energy Accelerators and Instrumentation at Cern during the week of September 13, to September 20, 1959. Briefly, it is a 6-BEV alternating gradient electron synchrotron, and the specifications for the machine are essentially the same as those described at the Cern conference. It is, however, probably significant to focus attention on the injector specifications. The injector consists of an S-band linear accelerator that has been subcontracted to the Metropolitan Vickers Company, of England. Injector specifications call for the following performance:

Energy	40 MEV
Energy deviation	± 0.5%
Frequency	2298 Mc
Current, Peak	125 Ma
Pulse length	1.2 Microseconds
Beam spot size	1 centimeter diameter
Angular beam divergents	$\pm 1 \times 10^{-3}$ Rad.

The accelerating gaps are to consist of either three- or five-cavity disk-loaded waveguide sections operating at a frequency of 499.67 Megacycles, which is the sixth subharmonic of the injector frequency. There will be a total of 16 such accelerating gaps in the machine. The present plans call for feeding the 16 gaps in a ring system driven by a single Eimac klystron that delivers 250-KW peak and 50-KW average power.

The injector current of 125-Milliamps peak is four times the current requirements of an A.G.S. at full energy. The factor of four allows for saftey and the possibility of high current at lower energy.

The DESY group are making good progress toward the completion of their machine. At the time of our visit, they had the injector building completed and approximately one-quarter of the concrete housing for the circular orbit of the machine had been poured. The building to house the synchrotron is expected to be completed by the first of October of this year. An apartment house for visiting staff has already been completed. Footings for the two beam-extraction buildings were being dug.

The first scale model of a magnet section has been completed and is now undergoing tests. Their present plan is to use the same Italian firm that made the magnets for the Cern machine.

They have a modulator and driving system set up and in operation with the Eimac 250-Kilowatt peak klystron. The RF setup is being used for power experiments with waveguide components. There has been difficulty with their present klystron in that the input cavity appears to have acquired a coating over the ceramic and it is not possible to drive the tube by using the first cavity. Consequently, the klystron is being driven by using the second cavity as the input cavity. Aside from the additional drive power required, little difference in the performance of the klystron has been observed. Fortunately, sufficient drive power was available so that no equipment modifications were required.

The first accelerator section gap model for the synchrotron has been made. The section was made by using the techniques which are patterned after Stanford's electroforming methods, and the section was electroformed by Elmore's Metall-A.G. in Schladern. The section has three cavities and has been vacuum tested and found to be vacuum tight. Roughly speaking, this section is about 18 inches in diameter and about four feet long. It weighs approximately 500 pounds, with a nominal $\frac{1}{4}$-inch electroformed copper wall over $\frac{1}{2}$-inch-thick loading disks.

The DESY group working with the gaps is in the process of learning the techniques of brazing OFHC copper. The use of hydrogen inside an assembly and in combination with torch brazing is completely new to them. We were asked to demonstrate the technique.

The vacuum group on the DESY project is evaluating a number of pump possibilities for application to the synchrotron. Among the pumps being evaluated is a molecular pump manufactured by the Arthur Pfeiffer Company of Wetzlar, Germany. Upon their specific recommendations, we made arrangements to visit the Pfeiffer Company at Wetzlar, which is very close to Schladern.

ELMORE'S METALL-A.G.

Elmore's Metall is a very old company, which started in business in the 1880's. It presently has 380 employees. Its products include electroformed copper shapes and all common copper geometries produced by drawing and extrusion. Elmore's Metall is presently building a new 6,250 sq. meter plant for producing sheet copper.

This firm is much like Revere Copper of Rome, N. Y., with the exception of the plating processes they use. The copper electroforming is used for sizes of tubing which are larger than their extrusion press capacity, which is about one foot in diameter. The plant has 300 cubic meters of plating solution and electroforms 200 tons of high-purity copper per year.

Elmore's Metall buy electrolitic copper which is then air melted and cast into anodes and the basic shapes commonly used for extrusion and drawing. The anodes for the plating baths are melted in an electric fired air furnace and cast in air. The anode is cast into about $2\frac{1}{2}$-inch cylinders that are approximately six feet long. The top slag that results in any such casting operation is left on the anode. The plating tanks themselves are large, being approximately eight feet wide, 40 feet long and six to seven feet deep. The tanks are lead lined and the anodes are laid on conductor rods in the bottom of the tank. Blocks of wood are used to establish a bearing height. The part to be electroformed, which is cylindrical in shape, is then placed horizontally on the bearing blocks which are at each end of the shaft that runs through the center of the cylinder. Half of the cylinder is in the solution and half is out of the solution. The cylinder is rotated approximately 15 to 20 RPM. An agate burnisher rides on top of the cylinder, which is in the air, and slowly travels back and forth over its entire length. The rate of motion of the burnisher is quite slow. There is approximately one square inch of agate in contact with the copper, and there is considerable pressure on the agate, since observation indicated that a 3/8-inch diameter steel rod holding the agate would flex as the agate rode over the length of the surface being plated. This technique is used for coating rolls used in the paper industry, with $1\frac{1}{2}$-inch copper. Some of these rolls are eight feet in diameter and 30 feet long.

Elmore's filter the solution, but did not tell us at what rate. However, they did say that the filtration rate is not critical. Observation indicated that there was no violent circulation in the bath. The only turbulence that could be seen was the slight turbulence due to the rotation of the cylinder in the bath as it plated.

There was very little crystallization at the edges and exposed surfaces of the bath and bearing. As a matter of fact, the only crystallization was at a few points along the bearing. These large vats were in rooms that had doors that were open and the wind could blow dust through the building. In general, the atmosphere that the baths were in was quite dirty.

In the maintenance of the baths, they use CP acid and tap water. They never change the solution and state that their present solution is 70 years old. Elmore's have been using essentially the same plating process for 80 years. The copper sulfate concentration is 40%.

We were shown some microphotographs of copper which had been electroformed onto natural copper crystal as it came from the mine. Before firing, the deposit had typical long needle-like crystals, and after firing at 800° C. for half an hour in hydrogen, the electroformed copper had the same appearance as the natural crystal from the mine.

Elmore's electroformed copper has an elongation of 35,756 PSI minimum, and goes up to 50,000 PSI maximum. The yield strength is 21,000 PSI.

Representatives of Elmore's stated that no addition agent was added to the plating solution. However, addition in various forms must be present, due to the age of the bath and the fact that wood blocks and other materials which would tend to leave impurities in the bath, have been used over a long period of time. They further stated that their target for plating speed was one Millimeter per week and that if plating is done faster, quality is lost. This statement was inconsistent with DESY's experience, in that the DESY section was plated at a rate of approximately 1½ Millimeters per week. Very little machining is required on the Elmore's deposits, even when the deposit thickness is in the order of 1½ inch.

An interesting aspect of the firm is that it is located immediately adjacent to the River Sieg and has its own generating plant which consists of a generator system capable of 700 KVA.

ARTHUR PFEIFFER COMPANY

The Arthur Pfeiffer Company has 250 employees; its products include mechanical vacuum pumps and positive pressure pumps, as well as complete systems for vacuum melting and vacuum evaporation of metal.

The principal performance charateristics of the Pfeiffer Molecular Pump are described in the attached reprint. This reprint is about two years old, and since it was written they have improved their measuring techniques and are now using an Alpert's type gauge and Veco amplifier.

The present pump has a pumping speed of 140 liters per second, and during the last year 11 pumps have been sold. The development of a 5,000-liter-per-second pump is under way.

We witnessed a demonstration of one of the 140-liter molecular pumps which was let down to dry air. Just prior to letting it down to dry air, the Veco gauge indicated a pressure of 1×10^{-9} MM. The pump was then let down to dry air and started pumping again. At the end of six and one-half minutes, the pressure was 10^{-7} MM. At the end of 30 minutes, the pressure was 10^{-8} MM, and it takes about a total of four hours, we were told, to get to 10^{-9} MM.

FRENCH ACCELERATOR AT ORSAY (SEINE ET OISE)

The design characteristics of this accelerator are well known, and ML Report No. 130 gives an excellent description of the Orsay project as of last September.

Our visit to the French accelerator was incidental, and occurred as a stop between Wetzlar, Germany and London, England.

The C.S.F. people report that the clamped-together construction technique for the inter-action structure used in this machine has been satisfactory.

To date, they have placed three 20-Megawatt sealed-off klystrons on the machine. One of these klystrons punctured its collector shortly after its installation, and the tube was filled with water. The second tube is still on the machine and the third tube was being installed the day we visited the project. Further, the C.F.S. people reported that they expected to have the machine completed by October of this year.

The experimental areas are in difficulty because of vertical radiation. Consequently a system of water tanks is now being installed over the present experimental area which will allow three to four feet of water for shielding. The halfway station which was originally planned is too small and will consequently be abandoned completely. The experimental bay at the end of the machine, according to the C.S.F. people, is also going to be abandoned and a new experimental room will be built which can be entirely shielded with earth. The original end-station area is going to be abandoned because of anticipated problems in shielding.

C.S.F. representatives state that a frequency stability of 10^5 is the maximum requirement for driver stability because temperature variations change the waveguide dimensions. They claim that 1° C. temperature change produces a dimensional change that corresponds to 10^5 frequency stability.

VICKERS RESEARCH LIMITED

Vickers Research is electroforming 6-MEV X-band accelerators and one-meter S-band accelerator sections, using techniques patterned after Stanford's electroforming methods. Their approach to electroforming is like Stanford's in that they are attempting to keep things very clean. Aluminum used for the spacers is pure aluminum, and they report that there has been little difficulty in machining it. The aluminum spacers for the X-band are commercially machined to a surface finish on the OD of 3-4 Microinches RMS.

Anodes are used only on one side of the plating tank. The anode compartment is formed by a diaphram which fits securely across the side of the tank. The per-hour filter capacity is equal to the tank volume. The cathode has a rotation and at the same time a translatory motion. The total time per cycle is 20 seconds, and the total rotation per cycle is 1600°. Distilled water and CP acid are used in bath make-up. However, technical grade copper sulfate is used. The aluminum spacers are not preplated with copper before stacking.

Vickers' X-band machine is nearing completion. They have already sold four. Price per machine is 3500 ₤ or approximately $98,000. All four have been sold in the British Isles. Two more are on order from outside the British Isles. Their machine delivers 6 MEV at a peak current of 40 Milliamps with a PRF of 600, and a pulse length of 1.7 Microseconds. The RF power is supplied by a one-Megawatt Feranti magnatron. The couplers for the X-band accelerator waveguide are silver brazed in hydrogen after the disk-loaded waveguide has been electroformed and etched. The medical mount for the machine is similar to the Metropolitan Vickers mount. A multiplate ion chamber is used for beam monitoring that delivers one Microamp or more, and hence they are able to use magnetic amplifiers rather than tubes in the beam-monitoring circuits. As a matter of fact, the whole unit has only six vacuum tubes in it, including the magnetron and the accelerator tube. The modulator switch is a triggered-spark gap.

There is still work toward a 100-MEV modulator unit machine design that could deliver one to six BEV. The Vickers people are optimistic about sponsorship for the Glascow Positron Accelerator.

ENGLISH ELECTRIC VALVE COMPANY

The English Electric Valve Company has been awarded a contract to supply klystrons to the Harwell S-band Linear Accelerator. This is the machine which was designed for one Ampere as a neutron-producing machine. The Metropolitan Vickers contract for supplying tubes for the accelerator has been cancelled and given to the English Electric Valve Company. The latter company currently has tubes on the Harwell machine, and the tubes that were delivered have worked satisfactorily. The klystron is a three-cavity klystron, delivering six-Megawatt peaks at nine Kilowatts average power. Other tubes at the English Electric Valve Company plant have exhibited some difficulties with the cathode seal due to punctures in the glass. A modification in the Corona Shields should correct the arcing problem. The RF output window is 707 glass sealed in kovar.

Paper presented by Chief Engineer W. Becker, of the A. Pfeiffer Company of Wetzlar, at the 1st International Congress for Vacuum Technology

A new molecular pump

In 1913 Gaede published his work about a molecular pump (figure 1).

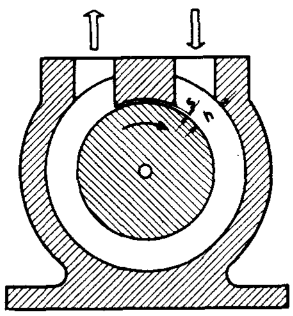

Fig. 1 Gaede molecular pump

The simplest construction here is a cylindric housing with an annular groove, which is interrupted at one spot, and a cylindric runner. The runner (rotor, armature) is made to rotate rapidly by aid of an external drive. The gases are in frictional contact with the cylindric rotor, become entrained and are moved in the direction of the arrow. One may switch several steps in series at this kind of arrangement, in order to increase the pressure ratio. One may replace several of such steps by using a helical groove; this was pointed out by Gaede already. Holweck later on improved this kind of construction, see figure 2.

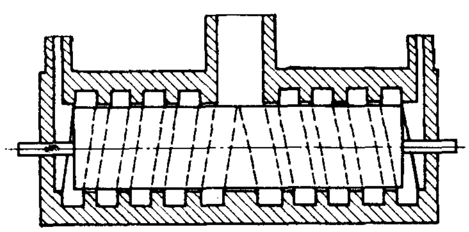

Fig. 2 Holweck pump

As between the rotor and the housing the air slit really has to be very narrow, Siegbahn suggested a construction at which expansion due to heat or centrifugal forces will affect the slit but little, figure 3. He replaces the cylindric rotor by a disk- shaped one, and here spiralic grooves are machined into the housing at both sides of the rotor.

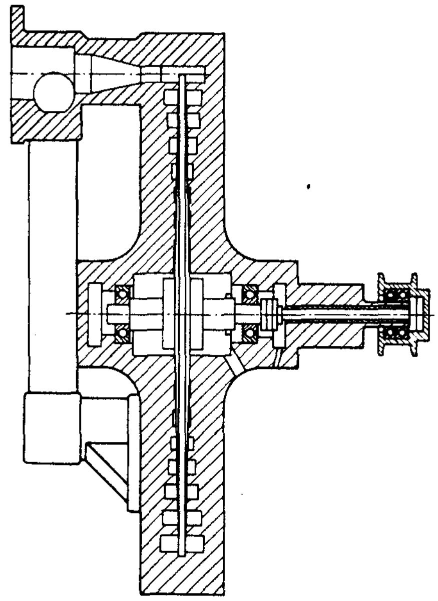

Fig. 3 Siegbahn pump

In spite of its attractive properties the molecular pump, irrespective of its construction, has not been applied much. The good properties are: The high vacuum free from vapors, the fast readiness for operation, no sensitivity against atmospheric pressure. The reasons why the pumps were employed so little are: the low speed of suction, especially if one keeps in mind how much of an aggregate one has to handle, the sensitivity against foreign bodies (dirt), and the danger of heat expansion.

The efficiency of a molecular pump at the pumps known up to now depends greatly upon the thickness of the closing slit (figure 1). Inside this slit s just as in the operating groove h gas is passed along due to the rotor friction and moves this way from a region of higher pressure into a region of lower pressure. The pressure gradient between the suction side and the pressure side will bring about an additional flow of gas. On the suction side the gas forwarded through the slit s expands, and this way puts a load on the suction side. If one calculates a molecular pump, then one will get e. g. a pressure ratio of $1:10^4$ for one step at an infinitely narrow slit. For practical employ one reaches much lower values, like the ratio of the depth of the operating groove h to the closure slit s. The pump therefore will have the better properties, the more narrow is the slit. The pumps known thus far operate with slit widths of 3/100 till 5/100 mm, and such narrow slits present a great potential risk: a sudden impact of air, which may deform the rotating cylinder by even this value, or a speck of dirt of the dimension of the slit, which reaches the pump, will cause a seizing of the rotor and thus a destruction of the pump.

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Our developmental work had the aim to create a molecular pump which may be operated with a rather large slit, and will reach a high pressure ratio with a high suction speed which is of the same order of magnitude as the one obtained with diffusion pumps. The high rpm are not the limiting factor, as many people think, if one has only provided enough play between rotor and cylinder, that heat expansion, sudden air impacts and small pieces of dirt cannot bring about any damage. I will only remind the listener that the modern kitchen machines, like mixers, show rpm's of 14000, and there are no difficulties encountered. At the drives of modern jet airplanes one even uses still higher numbers of revolution.

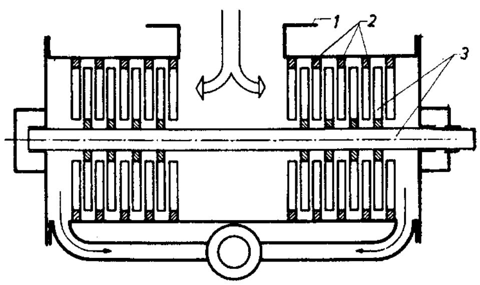

Fig. 4 Path of the gas through the new molecular pump

Figure 4 shows schematically the construction of the new pump. Inside the housing 1 are the stator disks 2 and the rotor 3. The stator disks are rigidly placed into the housing, whereas the rotor disks are arranged upon the shaft and are brought by this one into a high rotation. All disks contain inclined slots, and the ones inside the stator disks are arranged in a mirror- imagelike way to the ones inside the rotor disks.

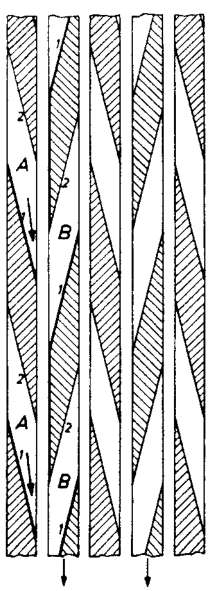

Fig. 5 Unrolling of the rotor and stator disks

In order to understand the operation better we look now at figure 5. This figure shows the evolution (unrolling) of some rotor- and stator disks. Let us look first of all upon a groove A in the first stator disk. Wall 1 forms with the total surface of the second rotor disk a wedgelike channel. Inside this one the gas is propelled in the direction of the arrow.

The wall 1 of the groove B in the rotor disk forms another channel with the surface of the stator disk, and here again a propelling action is noted. Simultaneously the wall 2 of the very same groove in the rotor disk forms a wedgelike channel with the surface of the next stator disk, and the gas is propelled again in the direction of the arrow. This process repeats at all the disks. If one selects rather thin disks, like those of a few mm thickness, then one gets in one disk rather short channels only and thus a small pressure ratio only, but one may place many pairs of disks into the pump, so that the overall pressure ratio still is quite high. At the small pressure ratio of a pair of disks the distance between the disks will affect the pressure ratio and the suction speed but little, so that the distance between the disks may actually be chosen as being one mm or even more, and the properties will hardly be affected. Simultaneously many channels operate in parallel. At the pump which I shall show in the next figures there are 40 channels, so that a high speed of suction is brought about. Radial slits between rotor and housing too may be made in 1 mm size, because the air flowing in due to the pressure gradient is still small in comparison to the suction speed. The pump shown has radially a slit of 1 mm, and the distance between the disks too is 1 mm.

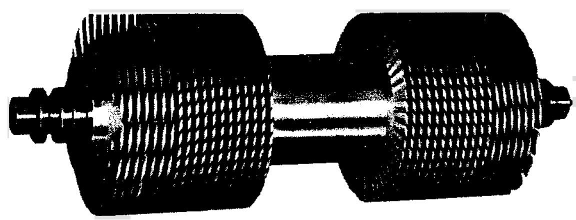

Fig. 6 The rotor

Figure 6 is a photograph of the rotor. If one selects the angle small under which the grooves are placed into the disks, then one gets a high pressure ratio at a small suction speed. If one, on the other hand, selects this angle as rather great, then one gets a small pressure ratio at a high suction speed. The disks which are directed towards the center of the pump show a great angle for a high suction speed, whereas the outer disks, which operate towards the pre-vacuum, show small suction speeds at greater pressure ratios.

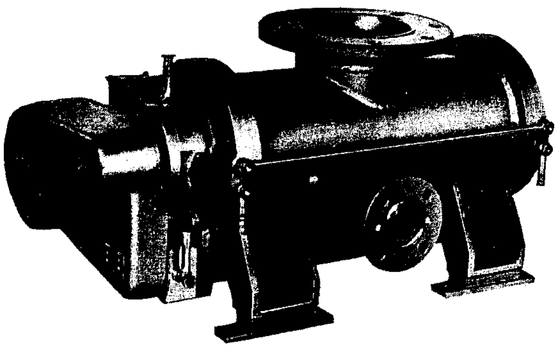

Fig. 7 The molecular pump TVP 509

Figure 7 shows an actual pump construction. The diameter of the rotor is 170 mm, the rpm is 16 000. The ball bearings are supplied by aid of a lift pump continuously with a stream of oil, so that lubrication and cooling are guaranteed. The drive occurs externally by aid of a belt drive, which is moved by an ordinary three- phase current motor of 0.3 kW.

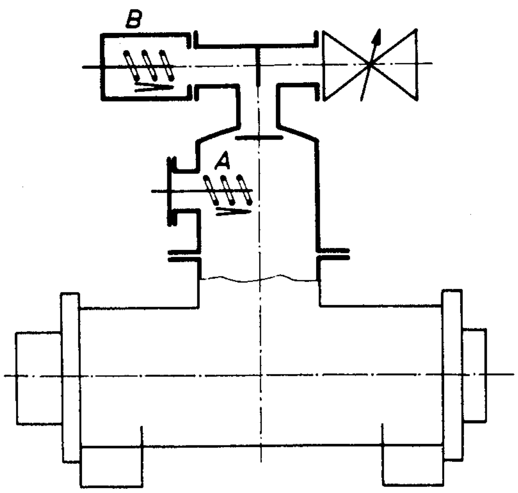

Fig. 8 Construction of the measuring devices

Figure 8 shows schematically the construction of the measuring devices. The whole setup is of welded steel with metal gaskets for seals. At the spots A and B we had placed the measuring system of an ionization vacuum gauge according to Alpert. On top, at the right side, is a needle valve, for the introduction of the gases. The connecting tube between the two measuring chambers is dimensioned like this, that at the full suction speed a pressure ratio between the two measuring spots of 1 : 8 is created and we calibrated the distance in the range from 10^{-4} till 10^{-6} Torr, because then we are able nicely to determine the amount of air admitted by the needle valve, by aid of a capillary flowmeter. At the lower pressures then we determined the ratio of suction from the pressure ratio at the two spots of measurement. The final vacuum reached in our experiments was 5×10^{-10} Torr. The residual gas was hydrogen.

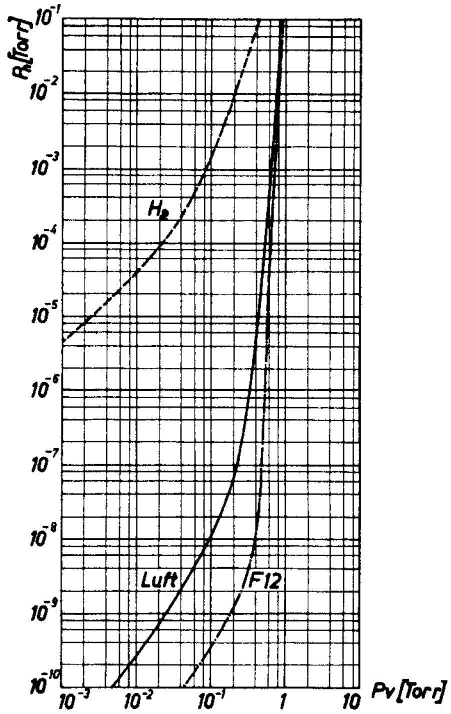

Fig. 9 High vacuum depending upon the fore-vacuum
H_2 = hydrogen Luft = air F 12 = Freon 12
Pv = fore-vacuum P_h = high vacuum

The next figure 9 shows how the high vacuum depends upon the preliminary vacuum (fore-vacuum). The curve 1 applies to air, the curve 2 to hydrogen, the curve 3 to the cooling agent F 12. At high pressures the pump has a rather low pressure ratio. Upon transition into the molecular realm the pressure ratio increases rapidly and reaches at the fore-vacuum of 10^{-2} Torr its maximum value. This one depends greatly upon the molecular weight of the gas to be pumped. The maximum pressure ratio at H_2 is 1 : 250, at air 1 : 5×10^7. The maximum pressure ratio for completely pure F 12 (FREON 12) is in theory much higher than the value shown in the diagram.

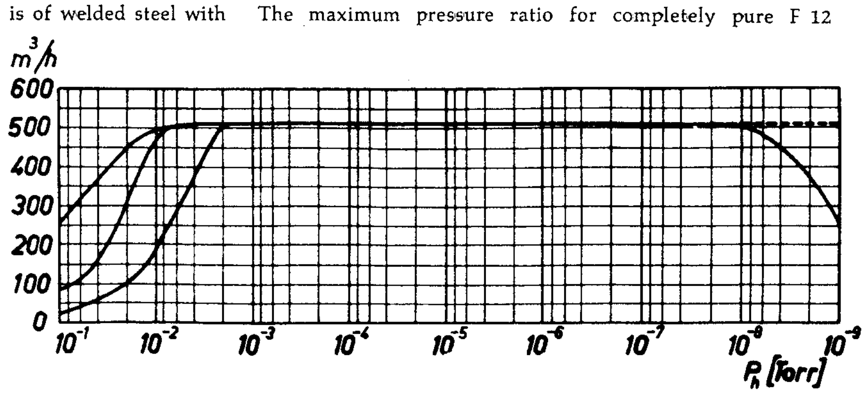

Fig. 10 Suction speed depending on the high vacuum with different backing pumps for air
Curves from left to right: backing pump 45 m³/h, 10 m³/h, 2.5 m³/h

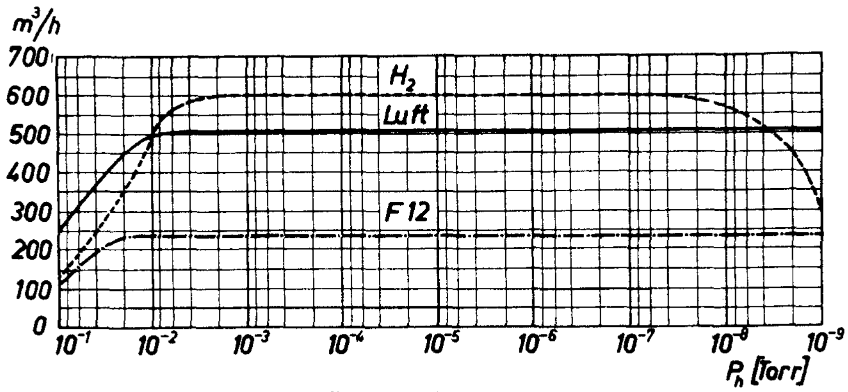

Fig. 11 Influence of the nature of the gas
H_2 = hydrogen Luft = air F 12 = Freon 12 P_h = high vacuum

The next figure 10 shows the suction speed of the pump as a function of the pressure at the high vacuum side, with a first pump for 45 m³ per hour. It is remarkable that the suction speed for H_2 lies above the suction speed of air, in spite of the fact that for H_2 a much smaller pressure ratio is operative. This higher suction speed is brought about like this that the flow resistance in the slits is much lower for H_2 than for air. And the pump gets for F 12 a smaller suction speed, because here the throttling inside the slits is greater. The suction speed of the air amounts from 10^{-2} till 10^{-8} Torr to constantly 500 m³ per hour, then it drops slowly. If one determines the suction speed for the partial pressure of air only, without the residual pressure (which is due th H_2) being taken into consideration, then the suction speed remains constant even beyond 10^{-9} Torr. The measured final vacuum was essentially determined by H_2, i. e. this one is the culprit, as it diffuses through the steel walls, or is released by same.

The next figure 11 shows the suction speed for air as a function of the pressure at the high vacuum side, at various pumps for the fore-vacuum. The upper curve is valid for a two-step pump combination of 45 m³ per hour suction speed, the center curve pertains to a two-step pump with 10 m³ per hour suction speed, and the lower belongs to a two- step rotating pump with a suction speed of 2.5 m³ per hour. As one is able to recognize, the suction speed changes only in the regions of higher pressures as a function of the fore-vacuum pump.

When constructing a vacuum setup in connection with the pump described one has not much trouble, especially if one intends to repeat an evacuation rather frequently. One may connect the pump directly with the receiver, without the intermediate placing of a valve, and the prevacuum pump too may be connected without any valve directly to the molecular pump. Both pumps may be switched-on simultaneously at atmospheric pressure. Till the time when the first pump has reached the region of about 10^{-1} Torr ... what requires about 5 minutes ... the molecular pump has reached already its complete rpm, and takes over the further pumping, down till the desired vacuum. A sudden onrush of air up till atmospheric pressure will not harm the pump. There is a slip- clutch at the motor, which sees to it that the motor is not overloaded. At atmospheric pressure a low rpm of the pump is established, which goes up, as the pressure drops, and will reach its full value at 10 Torr already. The molecular pump described may be applied there to best advantage always, where one must stress to get a vacuum free from oil, and the pump is superior to a diffusion pump in the region from 10^{-3} till 10^{-1} Torr, because at 10^{-2} Torr already it reaches its full suction speed.

Already now one may visualize new application possibilities of a new molecular pump, at which it will presumably be superior to the known high vacuum pumps:

— Manufacture of transmitter tubes of large sizes for highest frequencies
— Accelerators for nuclear physics
— Mass spectrometric high vacuum installations
— Melting setups for highest purities, like in the preparation of Ge and Si.

The pump should be valuable also for the separation of light isotopes. At normal H_2 it shows a compression ratio of 1 : 250, whereas at D_2, the heavy hydrogen, the ratio goes up to 1 : 2400, so that one may talk about a separation factor of 9.6.

Further experiments are in progress here.

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