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Southern California Chapter

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Special points of interest:

- Highlights from 2016 Equipment Exhibition
- Science Educator's Workshop Review from AVS Nashville
- Technical Paper: *"Project Hyperloop: Los Angeles - San Francisco transportation tube vacuum analysis"* By Dr. Vladimir Chutko of VECOR

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Project Hyperloop: Los Angeles—San Francisco Transportation Tube Vacuum Pumping Analysis"

By Vladimir Chutko, Ph.D.

Project Hyperloop is the project of high-speed transportation system where the passenger capsule rides in a tube with reduced pressure [1]. The original Hyperloop concept supposes that there should be a transportation tube from Los Angeles to San Francisco with the length about 560 km where the pressure about 1 mbar should be maintained. There are a number of other propositions of Hyperloop routes – Los Angeles – Las Vegas, Paris – Amsterdam, Cracow – Gdansk (Poland), and a number of companies developed those projects. At those companies websites you can find more or less detailed description of different project components, however there is no detailed information how their engineers are going to pump down the Hyperloop tube. Author have found just only source with analysis of Los Angeles – San Francisco - Los Angeles two tubes vacuum pumping [2]. It is shown there that using Busch R5 RA1600B 100 pumps with pumping speed 1600 m^3/hour placed at 6 km distance along the tube the Hyperloop tube pumping time to 2 mbar pressure is 5 days. We'll try to estimate if we can pump down the Hyperloop tube faster with modern powerful pumps and how many of them we need.

So, our goal is to pump down the tube with the length 560 km and diameter 2.5 m (we take it a little bit more than proposed passenger capsule diameter 2.43 m) from atmosphere to pressure 1 mbar. Let's suppose for simplicity that the tube is straight, made of material with negligible outgassing rate (outgassing rates of most metal and plastics conventionally used in vacuum engineering are in fact negligible in that range of pressures and at normal temperatures) and that there are no any leaks. Intuitively suppose that today it is practically impossible to pump down such tube with just one or two pumps or pumping systems located on the ends of tube or in its middle – the tube is too long, relatively narrow and its volume is about 2.7×10^9 liters = 2.7×10^6 m^3. A simple rough estimation using equation (1) [3]

$$t= 2.3(V/S_p)\log(P_0/P_t), \qquad (1)$$

where t – pumping time from initial pressure P_0 to pressure P_t, V the volume to be pumped down, S_p – vacuum pump pumping speed, shows that to pump such volume with a single pumping system from atmosphere to 1 mbar in 1 hour we need a system with pumping speed 1.9×10^7 m^3/hour, in 10 hours – 1.9×10^6 m^3/hour, and so on.... Let's place a number of pumps along the tube and see what happens.
We'll use a largest vacuum pump we could find in Internet – mechanical pump UV50 of Pneumofore (Italy) with the pumping speed 1834CFM = 3116 m^3/hour @ 60 Hz и 2641 m^3/hour @ 50 Hz, ultimate vacuum 0.5 mbar, inlet flange DIN200 (Dia.200 mm), and consumed power 90 kW for 60 Hz (Fig. 1) [4].

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SOUTHERN CALIFORNIA CHAPTER OF THE AVS : THE SCIENCE & TECHNOLOGY OF MATERIALS, INTERFACES, AND PROCESSING

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Upcoming Events

NCCAVS 38th Annual Equipment Exhibition

February 23, 2017

Holiday Inn
San Jose Airport
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ICMCTF '17
International Conference on Metallurgical Coatings & Thin Films

April 24-28, 2017

Town & Country Hotel
San Diego, CA

Chapter Activities

Science Educator's Workshop 2016 at AVS Nashville

Each year, AVS conducts a two-day in-service workshop on low-pressure experiments and modeling for middle and high school science teachers from the United States and Canada since 1990. The 2016 Science Educator's Workshop was held on November 6th to 8th in Nashville, Tennessee during the AVS 63rd International Symposium & Equipment Exhibition. The SCCAVS sponsored Kristy Marr of JH Hull Middle School in Torrance and Russell Cramm of Downey High School.

This year's SEW had 23 teachers from around the US at the workshop. Each morning was spent in classroom and lab activities ranging from simple demonstrations to longer experiments. Monday afternoon the group toured the laboratories at Vanderbilt University with Bridgett Rogers. Tuesday afternoon they toured the AVS Symposium Exhibit area. The schools of both teachers will be receiving a vacuum system from AVS.


From left to right: Tim Gessert (instructor) with Russ Cramm; Kristy Marr (far right)

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Chapter Announcements

Project Hyperloop (Cont'd)

Fig. 1. Vacuum pump UV50 of Pneumofore (Italy).
Pumping speed 2700 m^3/h @50Hz.

The pumping curves for UV series pumps are shown on Fig. 2. Pumps start to work at pressure 450 mbar, but on request may be supplied with atmospheric start pressure 1000 mbar.

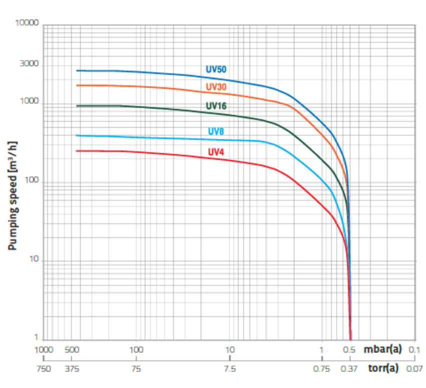

Fig. 2. Pumps Series UV pumping curves for 50 Hz power.

Project Hyperloop (Cont'd)

Let's place pumps uniformly along the length of Hyperloop tube and see what happens at different distances between the pumps. As well suppose that for each pump there is the valve between tube and pump. When the valve is open, it works just like a short nipple Dia.200 mm x 100 mm length (approx. like a standard gate valve with flange Dia.200 mm).

We'll use our vacuum engineering software VacCAD1.0 [5] for the analysis. We also make the following assumptions (Fig. 3). We divide the entire Hyperloop tube into the equal sections A_1, A_2, …, A_i, …, A_{N-1}, A_N. Then we analyze the pumping of each section with a single pump independently of other sections – like as all the sections are separated by walls. At simultaneous operation of all pumps, the pumping time of a single section to a given pressure is equal to the time of pumping of entire tube to the same pressure. Therefor, we can analyze just a single section pumping.

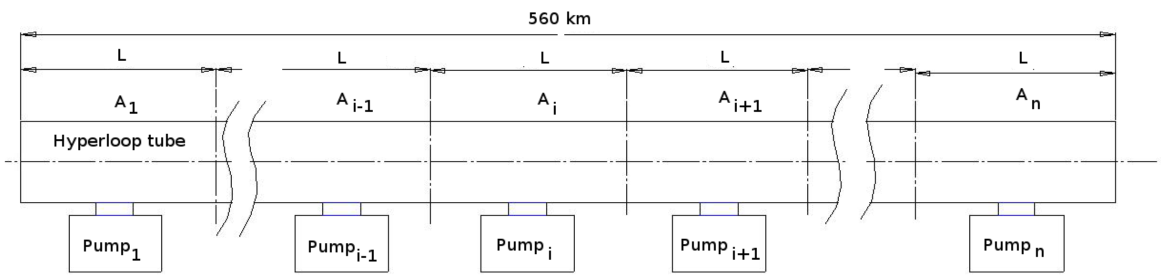

Fig. 3. Hyperloop tube pumping model

(Continued on additional pages 7-9)

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Suppose that the Hyperloop tube is made of stainless steel. Extend the UV50 pumping curve (Fig. 2) to atmospheric pressure 1000 mbar and enter UV50 pump data into the VacCAD 1.0 database. VacCAD1.0 shows the UV50 pumping speed (in liter/s) it will use for analysis (Fig. 4).

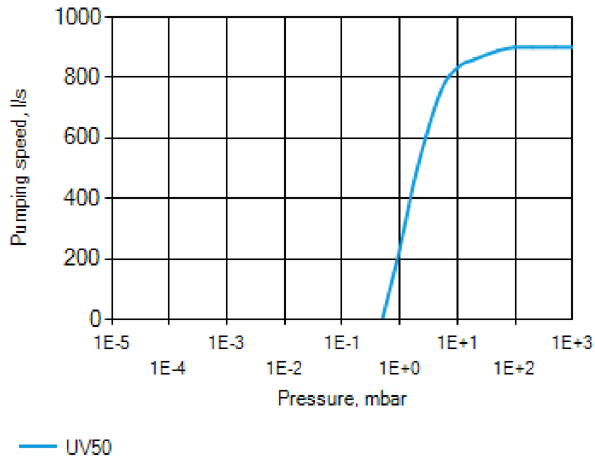

Fig. 4. Pump UV50 pumping speed.

Enter in VacCAD 1.0 our vacuum valve as Roughing Hose Dia.200 mm x 100 mm. VacCad1.0 calculates its conductivity (Fig. 5). As expected, in our pressure range 1000 mbar – 1 mbar (viscose range of gas flow) the conductivity is very high and won't limit the pumping speed.

Let's begin our analysis with the distance between pumps L = 100 m. In our simulation it is the pumping of cylindrical vacuum chamber Dia.2500 mm and 100 000 mm = 100 m length made of stainless steel. The calculated pumping curve is shown on Fig. 6 as a dark-blue line. Therefore 5600 pumps UV50 (560 km : 100 m = 5600) pump down the Hyperloop tube from atmosphere pressure to 1 mbar vacuum in about 5000 s = 1 h 23 min, and can pump down the tube to the ultimate pressure 0.56 mbar.

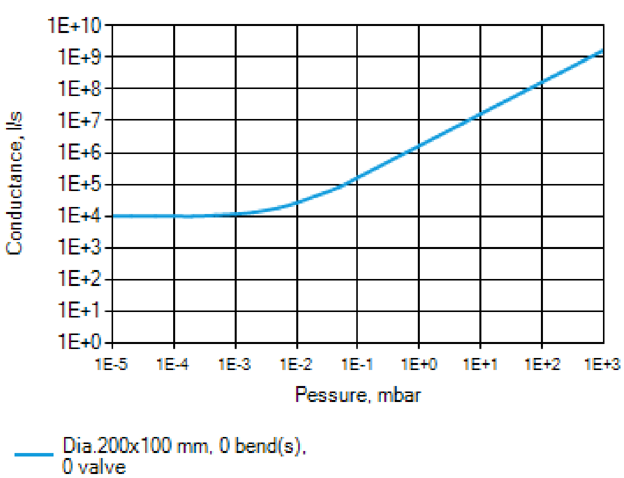

Fig. 5 Vacuum valve conductivity.

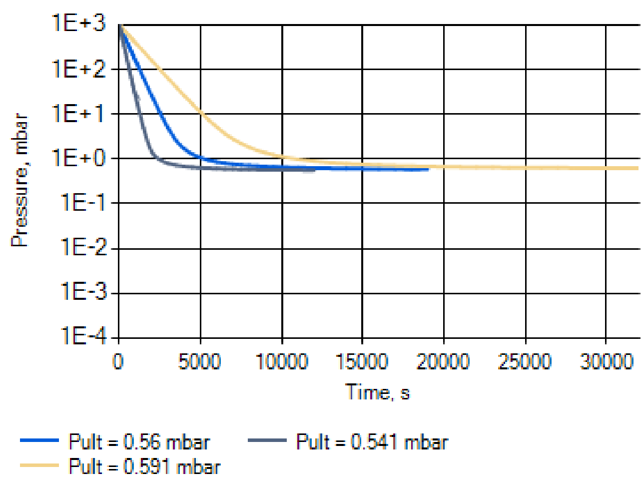

Fig. 6. Calculated Hyperloop tube pumping with different numbers of UV50 pumps.

Let's try to decrease number of pumps in two times placing them at distance 200 m from each other. In that case the total pumps power decreases as well in two times. However Hyperloop tube pumping time increases up to 10 000 s, or almost 3 hours (yellow line on Fig. 6).

And, just to complete the analysis, let's place pump on the distance only 50 m from each other. As a result, we obtain fast pumping in 40 min (gray line on Fig. 6), total power of 11 200 pumps equal to 1008 MW.

Note, that consumed electrical energy doesn't depend on number of pumps and is equal to 675 MW-hour per a single pumping.

Discussion and Conclusion

Our results allow make the following conclusions:

- 5600 pumps with a total consumed power 5600 x 90 kW = 504 MW consume 675 MW-hour electricity for just a single Hyperloop tube pumping during 1 h 23 min. For comparison - in 2014 an average American household annual electricity consumption was 11 MW-hour. Therefore all those pumps require just for a single Hyperloop tube pumping consume the same energy as 61 American households consume in an year!
- Consumed per pumping electrical energy doesn't depend on number of pumps;
- Pumping time is approximately inversely proportional to number of pumps and their pumping speed;
- We didn't find data or recommendations regarding UV50 pumps service period. However we can suppose that in hot California and for pumps located outdoors it would be necessary to check and test the pumps at least one time in three month. Assuming that that testing needs about 1 hour, we can conclude that in a single shift (8 hours) it is possible to test 6 pumps (taking into account the distances between pumps, preparing works, etc.) or 540 pumps in three month (90 days). Therefore we need at least 10 service teams located 54 km (540 x 100 m = 54 000 m = 54 km) from each other, which will serve those pumps continuously and with no breaks! In case of 200 m distance between pumps we'll need only 5 service teams (nevertheless for continuous work!), and in case of 50 m distance - 20 service teams located along the tube over 27 km for continuous pumps service.

Unfortunately, we couldn't repeat the calculations of [2] using our VacCAD1.0 software, because VacCAD1.0 is intended for a regular industrial vacuum systems engineering and simulation, and if calculated pumping time exceed 30 hours, it stops and recommends to replace vacuum pump for more powerful one. Nevertheless, we can compare our results with a simple estimation – if we replace our UV50 pumps 3200 m^3/h with Busch R5 RA1600 1600 m^3/h 37 kW @60 Hz pump, we increase the pumping time approx. in 2 times. Placing pumps on 6000 m distance instead of 100 m, we increase the volume of each section in 6000 : 100 = 60 times, and pumping time must increase in approx. 60 times. So we'll pump down the tube to pressure 1 mbar during 1 h 23 min x 2 x 60 = 166 hours. Pumping to pressure 2 mbar as in [2] will take about 1 h 02 min (see Fig.6) x 2 x 60 = 124 h.

It is almost the same 125 hours calculated in [2] for final pressure 2 mbar. However we need to take into account that used in [2] estimation formula (1) supposes that pumping speed is the same over the whole pressure range 1000 mbar – 1 mbar. In fact, it decreases fast below a few millibar pressure , and a real pumping time is more than calculated with formula (1). For our case calculated by (1) pumping time for UV50 pumps located at 100 m distance from each other (pumped volume is 490,9 m^3) to pressure 2 mbar is approx. 54 min; VacCAD1.0 takes into account non-constant pumping seed and gives pumping time 1 h 02 min, i.e. 15% more (A. Berman [3] recommends use coefficient 1.5 for pressure range 6.7×10^{-1} mbar < P < 13 mbar). Applying the same rate for pumping time 125 hours [2], we obtain 144 hours pumping time to 2 mbar. So we can compare our results and results [2] as close enough with difference about 15%.

Electrical energy needed to pump down the Hyperloop tube to pressure 2 mbar with our 90 kW UV50 pumps is 520 MW-hour. Taking into account described above correction rate 15%, total calculated in [2] energy needed to pump one tube to pressure 2 mbar is 430 MW-hour. It is expected result because the specific power – electrical power per unit of pumping speed, - is 23.1 W/(m^3/h) for R5 RA1600 and 28.9 W/(m^3/h) for UV50 pumps.

Therefore the Hyperloop tube pumping system design depends on time specified for tube pumping. With a modern pumps we can realize pumping to specified pressure 1-2 mbar in the time range from about an hour to a week. Fast pumping requires thousands pumps and cost of equipment and operation rises sharply. Total energy needed for tube evacuating is a constant value for a given pumps and doesn't depend on pumps number, but depends on pumps specific power (power to pumping speed ratio).

Note that both described above analysis are ideal cases analysis, reality can only be worse. Possible leaks in so long and big tube, contamination, vacuum pumps oil vapors can significantly deteriorate the vacuum system performance. Usage of oil traps significantly decrease the pumping speed. Besides, the specified ultimate pressure of both estimated pumps is just a little bit less than the target pressure 1 mbar – 0.5 mbar for UV50 pump and 0.3 mbar for R5 RA1600 pump. This is not good – a regular pump wear leads to pump ultimate pressure deterioration and it can be more than 1 mbar.

To obtain a specified vacuum inside the Hyperloop tube the pumping down from atmosphere to pressure 1 mbar is just a first step. The second step is to keep pressure at that level. Of course, we can install air locked chambers on the ends of tube for capsule loading/unloading and, if necessary, in a few places along the tube for service and maintenance and use pumps with gate valves (in fact the gate valve is necessary component allowing to remove pump out of the system for maintenance, repair, or replacement without stopping the system). In ideal case these measures allow pump the tube down to specified vacuum, close the pumps gate valves and enjoy with obtained vacuum. In a real life vacuum immediately begins to deteriorate – a phenomenon familiar to all vacuum engineers and technicians. We don't know anything about the real tube design and can't estimate that process speed, but as in any vacuum system the pumps must work either permanently or periodically to keep the pressure at specified level 1-2 mbar, and consumption of electrical energy rises significantly.

More powerful pumps would allow obtain the same pumping time with fewer pumps. Edwards has developed mechanical vacuum system for steel degassing with pumping capacity of 1,000,000 m^3/hr at 0.67 mbar (Fig. 7) [6]. The use of such systems would reduce the required number of pumps or pumping time by 320 times comparing with UV50 pumps! Hence instead of 5600 pumps considered above we can use only 18 those huge Edwards pumping systems placed on the distance 31 km from each other. Unfortunately author couldn't find any detailed specifications of that pumping system for more detailed analysis.

Fig. 7. Edwards mechanical pumping system with pumping speed 1,000,000 m^3/hour [6].

In fact, the pumping of so long (31 km) and relatively narrow (Dia.2.5 m) pipe should take more time because the pipe conductance is compared with the pump pumping speed. The conductance of a straight pipe Dia.2.5 m x 15,500 m length (one half of distance between two pumps) reduces linearly from about $7x10^8$ m^3/hr at atmospheric pressure to $7x10^5$ m^3/hr at 1 mbar pressure (calculated with VacCAD1.0 software). It means that the pumping speed in the center of pipe between two pumping systems with nominal pumping speed 10^6 m^3/hr decreases approximately about 2.5 times from 10^6 m^3/hr at atmospheric pressure to 410,000 m^3/hr at pressure 1 mbar.

The author thanks Mr. Richard MacFarlaine for the discussion that helped in this work.

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