Calculation No: NSTXU-CALC-33-03-00 **Revision No:** 1

Title: Calculation of TVPS TMP Backing System

Purpose of Calculation:

Evaluate the effective pumping speed to maintain the TMP backing pressure at a satisfactory level under all operating conditions.

Codes and version: Microsoft excel 2010

References:

Vacuum Technology, 3rd edition, A. Roth

Assumptions:

Worst case: opening a TMP at 30 mT air during pumpdown of the NSTX-U vacuum vessel.

Calculation: (Calculation is either documented here or attached)
See attached report

Conclusion: (Specify whether or not the purpose of the calculation was accomplished)

The EBARA ESA70 dry pump and foreline design have an effective pumping speed of 124 L/s which is well above the required 27 L/s required under the most stringent conditions for the backing system.

Cognizant Individual (or designee): William Blanchard W. Blanchard Digitally signed by W. Blanchard Date: 2018.09.13 07:06:42 -04'00'

Preparer: William Blanchard W. Blanchard Digitally signed by W. Blanchard Date: 2018.09.13 07:07:20 -04'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker: Dang Cai: Dang Cai Digitally signed by Dang Cai DN: cn=Dang Cai, o=PPPL, ou=Engineering, email=dcai@pppl.gov, c=US Date: 2018.09.12 16:40:52 -04'00'

National Spherical Torus eXperiment - Upgrade

NSTX-U

Calculation of TVPS TMP Backing System

NSTXU-CALC-33-03-00 - Rev 1

1/11/18

W. Blanchard Digitally signed by W. Blanchard Date: 2018.01.11 10:39:39 -05'00'

Prepared By
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Approved By – Responsible Engineer
D. Cai

NSTX-U CALCULATION

Record of Changes

Rev.	Date	Description of Changes	Revised by
0	1/5/18	Initial Release	
1	1/11/18	Add calculation for stored energy and pump down time	W. Blanchard

NSTX-U Calculation Form

Purpose of Calculation:

Evaluate the effective pumping speed to maintain the TMP backing pressure at a satisfactory level under all operating conditions.

References:

Vacuum Technology, 3rd edition, A. Roth

Assumptions:

Worst case: opening a TMP at 30 mT air during pumpdown of the NSTX-U vacuum vessel.
TMP pumping speed is ~1800 L/s at 30 mT
Throughput is Q=1800 L/s* 0.03 = 54 T*L/s.
To maintain 2 T behind the TMP requires an effective pumping speed of (Se) of 27 L/s (Pressure P=Q/Se => Se=(54 T*L/s)/(2 T)=27 L/s).

Calculation:

1) Sp, backing pump speed (EBARA ESA70) at 2 T=140 L/s
2) Conductance C for air in viscous flow => $C=182(D^4/L)Pavg$
3) Diameter D in cm, Length L in cm, Pavg in T and C=L/s
4) In series effective conductance $1/Ce=(1/C_{1})+(1/C_{2})+(1/C_{3})+\ldots$
5) Effective pumping speed 1/Se=(1/Sp)+(1/Ce)

Foreline:

	Inner Tube Diameter D (cm)	Length L (cm)
C_1	14.63	700
C_2	9.73	400
C_2	4.75	55

At Pavg= 1T:
From 2) above: C_1=11,900 L/s
C_2=4078 L/s
C_3=1685 L/s

From 4) above: C_{e1}=(11,900*4078)/(11,900+4078)=3037 L/s
Ce=(3037*1685)/(3075+1685)=1084 L/s

From 5) above: Se=(140*1084)/(140+1084)=124 L/s

Conclusion:

The EBARA ESA70 dry pump and foreline design have an effective pumping speed of 124 L/s which is well above the required 27 L/s required under the most stringent conditions for the backing system.

Purpose of Calculation:

Evaluate the stored energy in the backing line (ES-Mech-15)

References:

Pressure Systems Stored Energy Threshold Risk Analysis, S. S. Paulsen (PNNL), p. 2.2, eq. 2.2

Assumptions:

Worst case: 15 PSIG of nitrogen when pumping down vacuum vessel

Calculation:

1) Compressed gas stored energy $Es=((P*V)/(k-1))*(1-(P_0/P)^{(k-1)/k})$
Where:
P=vented pressure=15 PSIG=29.7 PSIA=4276.8 lb/ft^2
V=volume of backing line=5.03 ft^3
k(air and nitrogen)=C_p/C_v=1.4
P_0=atmospheric pressure=14.7 PSIA=2116.8 lb/ft^2

2) P*V=21,512 ft*lb
3) k-1=0.4
4) (P*V)/(k-1)=53,780
5) P_0/P=0.495
6) (k-1)/k=0.2857
7) $(P_0/P)^{(k-1)/k}$ =0.818
8) $(1-(P_0/P)^{(k-1)/k})$=0.182
9) multiplying 4) by 8): $Es=((P*V)/(k-1))*(1-(P_0/P)^{(k-1)/k})$=9788 ft*lb

Conclusion:

Under the worst case conditions, the backing line has a stored energy less than the 10,000 ft*lb specified in ES-MECH-15.

Purpose of Calculation:

Evaluate the pumpdown time of the NSTX-U vacuum vessel to 30 mtorr using the TVPS dry backing pump.

References:

Vacuum Technology, 3rd edition, A. Roth

Assumptions:

1) Ebara effective pumping speed (Se) graph for dry pump ESA70 and a roughing line of 6" dia tube (250" length) in series with 4" dia tube (130" length) (attached).
2) NSTX-U volume (V) ~ 28,300 liters

Calculation:

Pumpdown time T from P1 to P2: $T=V/Se*\ln(P1/P2)$

Approximating Se from the graph:
$Se\sim 25$ l/s for 760 torr to 100 torr; $T_1=28{,}300/25*\ln(760/100)=2296$ seconds (38.3 minutes)
$Se\sim 18$ l/s for 100 torr to 35 torr; $T_2=28{,}300/18*\ln(100/35)=1650$ seconds (27.5 minutes)
$Se\sim 67$ l/s for 35 torr to 10 torr: $T_3=28{,}300/67*\ln(35/10)=529$ seconds (8.8 minutes)
$Se\sim 128$ l/s for 10 torr to 1 torr: $T_4=28{,}300/128*\ln(10/1)=509$ seconds (8.5 minutes)
$Se\sim 108$ l/s for 1 torr to 0.03 torr: $T_5=28{,}300/128*\ln(1/.03)=919$ seconds (15.2 minutes)
Time to pump from atmosphere to 30 mtorr $T\sim 98$ minutes

Conclusion:

Time to rough down NSTX-U from atmosphere to 30 mtorr is less than the 2.5 hrs (150 minutes) as indicated in the requirements document, NSTX-U-RQMT-RD-016-00.