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"Thickness and Shape Optimization of Filter Sheet by Non-Linear FEA"

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Abstract - Filter Sheets are non standard components and hence the guidelines for design are loose under the ASME and the TEMA code. The usual engineering practice is to extend the ever current design is available with an increased factor of safety. However this results in excessively heavy designs, resulting in increasing costs (e.g. Material, transport, assembly and installation).Hence in such designs there is maximum scope for optimization. Optimization goals are focused on Installing maximum possible filter tubes in a single plate thus increasing the capacity – Shape Optimization and Designing an optimal thickness for filter sheet assembly component for maximum economy – Material optimization. The Project execution phases consist of Analyzing a proposed for both Shape and Material optimization and submission of reports to clients, (In this phase we analyze only 1/6th portion of the assembly) Based on approval and feedback of client, designing the entire assembly and submitting drawings and models for approval) On approval of client proceed with analysis of the entire model created in phase 2. Performing actual hydro tests on the assembly after manufacturing, and evaluating effectiveness of FEA analysis. Preparing Information sheets and guideline processes for future project implementation. The challenges for FEA validation are Performing Shape Optimization and making filter pattern in accordance with manufacturability and ergonomic evaluations. FEA validation should certify a FOS of 5, as required by the guidelines of the Saudi Arabia Oil Code. FEA validation being comparable in case of Hydro Test performance on actual installation of assembly. The outputs of FEA work shall be a shape Optimized Filter Sheet assembly, with maximum productivity and maximum economy. Deformation and Stress Certification for performance in Hydro Test which shall take place at 2.5 times the actual working conditions.

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THICKNESS AND SHAPE OPTIMIZATION OF FILTER SHEET BY NON-LINEAR FEA

Strictly as per the compliance and regulations of :

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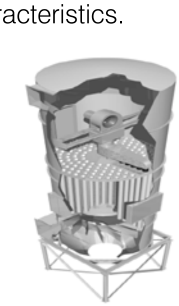
I. Introduction

Filter Sheets are non standard components used in Oil & Natural gas Industry for filtration. The usual engineering practice is to extend the ever-current design is available with an increased factor of safety. Around the world, for environmental reasons, oil refineries equipped with a Filter Unit have to face the challenge of particulate emission reduction. The refinery would not be able to meet the tighter limits with its existing Filter Unit flue gas cleanup equipment. The 3rd stage blowback filter option would enable industries to meet current particulate emission requirements and also get close to if not already meet particulate emission a number of years in advance of 2010 requirements. Existing tube sheet Filter assembly as shown in fig.1 have less filtration capacity due to less number of filter tubes. Existing assembly model design is less advanced and flexible. We are going to increase the number of filter tube for increasing the filtration capacity.Fig.2 shows proposed tube sheet assembly with increase number of tubes. The filtration capacity of proposed design can improve by using optimum pitch layout for filter candle. So to optimized the shape and weight of proposed filter sheet assembly considering various design constraints without affecting their functional characteristics.



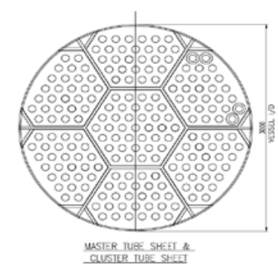


Fig. 1 : Existing filter sheet *Fig. 2 :* Proposed sheet

Due to Coagulation in filter, the Internal pressure increases with time. Due to this internal pressure, the tube sheet in filter is deflected for some time it will break and the joint break. Ignition temp of Natural gas is around 300^{0}C .The impurities which are present in it having temp near about 110^{0}C. In Middle East Region, during operation due to high temp it gets ignited and Explosion of overall plant is there. To avoid this model of the tube sheet is require to improve. Finite element based modeling is the best way to improve model of tube sheet assembly. Analysis require for Validation of FEA results with tested (actual) results. After validation we have base for modeling and simulation of proposed assembly.

The proposed filter unit contains seven chambers as shown in fig3.It has six circular sector filter sheets and one central hexagonal filter sheet. The thickness of the chamber wall depends upon Internal working pressure, factor of safety and Welding allowances. The filter sheets consist of holes in which filter candles are inserted. The capacity of filtration depends upon the number of candles used in filter sheet assembly. The central Hexagonal filter sheet has no input system so it is not a part of analysis.

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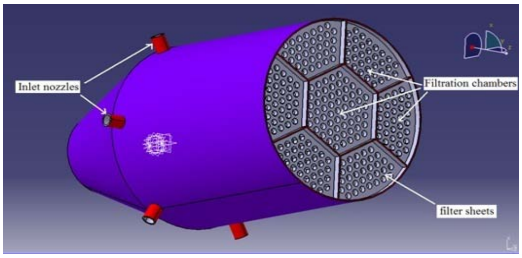


Figure 3 : Proposed model of air filter unit

This entire unit is divided into seven different chambers. The central, hexagonal chamber has more filtration capacity than others. Each chamber is intented to filter a different gas allowing primary mixing of these gases. Inlet nozzles are provided to each chamber. Each inlet has flow control valve to control the flow of gas, thus enabling the control of percentile of each gas. Special filter candles, which remove flue gas particles as small as 2 micron, are proposed to be employed. The filter elements should be removed if the dirty filter P (differential pressure) is higher than the 0.7 bar as per operational guidelines. The refining industries require to design and analyze the filter assembly for achieving following properties: –

a) High mechanical strength for longer filter life
b) Low pressure drop for less interruption of process flow.
c) Clean ability by pulse jet or back flushing to reduce maintenance costs.
d) Increased filtration area, particularly with pleated elements.
e) Increased dirt-holding capacity.
f) Low in weight & Low implementation cost.

Fig-4 shows the four pitch pattern. Among the four we select the 60^0 pitch pattern. The Design of proposed filter sheet are based on the following assumptions:

i) The plate is flat, of uniform thickness, and of homogeneous isotropic material.
ii) The thickness is not more than about one-quarter of the least transverse dimension, and the maximum deflection is not more than about one-half the thickness.

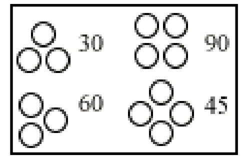


Figure 4 : Pitch Pattern

iii) All forces-loads and reactions are normal to the plane of the plate.
iv) The plate is nowhere stressed beyond the elastic limit. For convenience in discussion, it will be assumed further that the plane of the plate is horizontal.

a) Manufacturing and Testing

Manufacturing of the filter sheet is done by Casting and machining .In machining the holes are Drilled and Reamed, then applying the Heat treating process. In Gulf countries they preferred Gas cutting or Rolled plates. For testing of Filter sheet, Non-Destructive Ultrasonic Testing machine is used. In other words, NDT allows parts and material to be inspected and measured without damaging them. Fig 5 shows different parts.

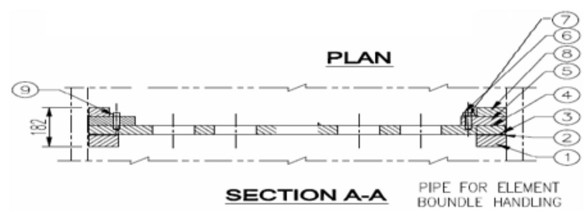


Figure 5 : Section of Filter sheet

Table 1 : Part list

9	LOCKING PIN	SS 304	Dia16x 75 lg	6	REMOVABLE
8	TOP SUPPORT	SA 516 Gr.70	40 thk	4	WELDED TO SHELL
7	WASHER(M16)	SS 304	M16 (spring)	2	STD
6	ALLEN BOLT	SS 304	Dia16x 60lg	2	STD
5	PACKING PLATE	SS 304L	40 thk	4	REMOVABLE
4	FILTER SHEET	SA 240 TYPE 304L	40 thk	1	REMOVABLE
3	SQ.GASKET	RUBBER	Sq. 8X8	1	GLUID TO TUBE SHEET
2	GASKET PLATE	SS 304L	12 thk	1	REMOVABLE
1	BASE SUPPORT	SA 516 Gr.70	50 thk	1	WELDED TO SHELL
P.N.	DESCRIPTION	MATL	SIZE	QTY	REMARKS

b) Boundary Conditions

Non-Linear Analysis of filter sheet is done by applying the following different seven conditions, for the same we consider $1/6^{th}$ portion of the filter sheet as shown in fig.

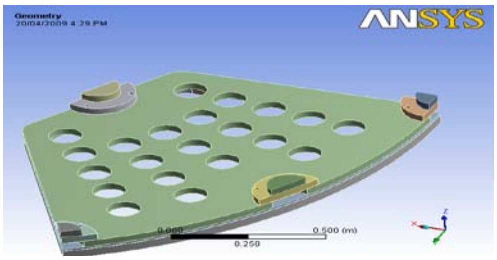


Figure 6 : Filter sheet assembly with different parts

1. To be analyzing given filter sheet for its self weight.
2. To be analyzing given filter sheet for differential pressure of 0.07MPa without self weight.
3. To be analyzing given filter sheet for differential pressure of 0.07MPa with self weight.
4. To be analyzing given filter sheet for hydro test with 2.5 times of given pressure of 0.07 MPa without self weight.
5. To be analyzing given filter sheet for hydro test with 2.5 times of given pressure of 0.07 MPa with self weight.
6. To be analyzing given filter sheet for back pressure of 0.07 MPa without self weight.
7. To be analyzing given filter sheet for back pressure of 0.07 MPa with self weight.

Top support and base support are welded to the shell. Therefore these are act as a fixed support.

c) Non-Linearity

Nonlinear structural behavior arises from a number of causes, which can be grouped into these principal categories: Geometric Non-linearity, Material Non-linearity, Contact Non-linearity.

Contact forms a distinctive and important subset to the category of changing-status nonlinearities. When two bodies comes in contact but Homoginity is lost, Contact Non-linear Analysis is there and force is transmitted from one body to other body. In this project we have different materials Stainless Steel (SS), Structural steel (SA) & Neoprene rubber. Neoprene rubber has material nonlinearity as shown in following graphs.

There are five types of Contact Non-Linearity, these are-

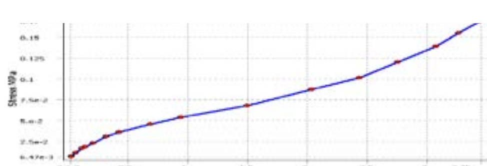


Figure 7 : Neoprene Rubber > Biaxial Test Data

Always Bonded (Welded), Bonded (Glued joint), Standard contact, Sliding (No Separation), No Separation (Always).

In Locking Pin, there is No Separation type of Contact. Body cannot have loose contact. It is generally sliding in a groove. It only applies to regions of faces. In Top Tupport, there is Always Bonded (Welded) type of Contact. It behaves always as a linear. In Packing Plate, there is No Separation type of Contact. Body cannot have loose contact. It is generally sliding in a groove. It only applies to regions of faces. In Square Gasket, there is No Separation (always) type of Contact. Body cannot have loose contact. It is generally sliding in a groove. In Filter sheet, there is Bonded (Glued joint) type of Contact. This is the default configuration for contact regions. If contact regions are bonded, then no sliding or separation between faces or edges is allowed. In Gasket Plate, there is No Separation type of Contact. Body cannot have loose contact. It is generally sliding in a groove. It only applies to regions of faces. Separation of faces in contact is not allowed, but small amounts of frictionless sliding can occur along contact faces. In Base Support, there is Always Bonded (Welded) type of Contact. It behaves always as a linear.

II. Meshing of Filter Sheet Assembly

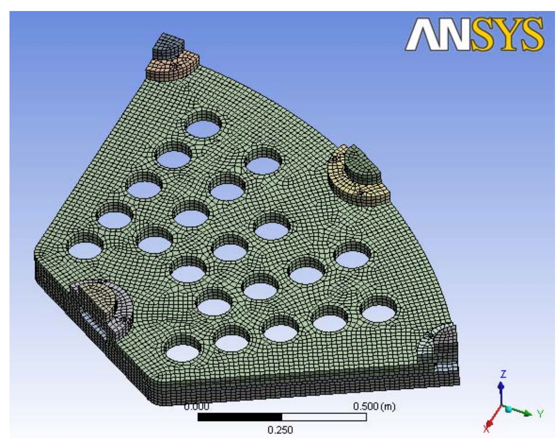


Figure 8 : Meshed model of Filter sheet

Solid 95 is a higher order version of the 3-D 8-node solid element. It can tolerate irregular shapes without as much loss of accuracy. Solid 95 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. In this project work, the filter sheet assembly model is meshed with hexahedron elements as shown in figure. Mapped face Meshing is given to 21 holes in the filter sheet as well as Base support. Filter sheet assembly along with all the parts are meshed as shown in fig 8 with Hex-dominant and Aesize given to 15mm or 0.015m. The elements created are 28401 whereas number of nodes present are 126636.

After meshing is done, solve this model for different seven conditions, different values for stress and deformation is there. Filter sheet is to be analyzed by different seven condition. Figure 9 shows the five different point at which the Stress value is maximum near at the base support for the worst condition i.e. at Hydro test –without weight which is having maximum stress value among all the conditions and fig-10 shows maximum deformation for worst condition.

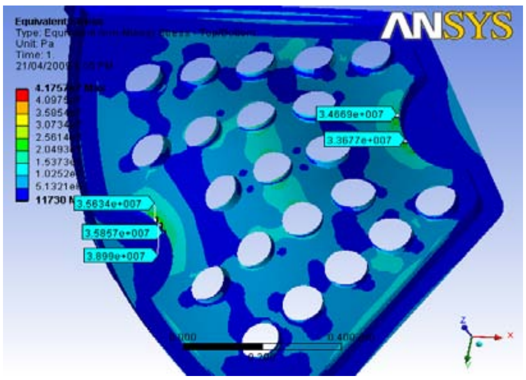


Figure 9 : Five points where stress value is maximum

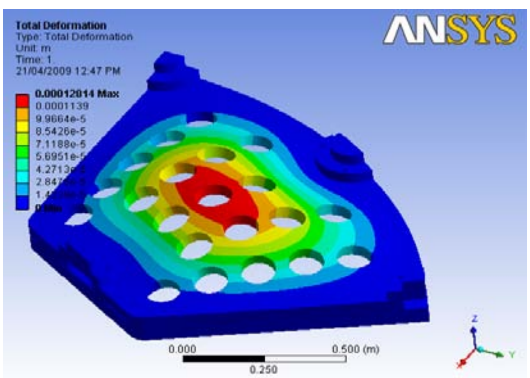


Figure 10 : Maximum Deformation

Result: Maximum Equivalent Stress=4.1757 e7 Pa
Maximum Deformation=.00012814 m

III. Mass Modeling

In filter sheet assembly, filters are to be hanged on filter sheet. These filters are shown as a mass model. The mass model is modeled by using RBE3 (Rigid Body Element).Figures 11 show the Filter tube sheet Assembly with considering the weight of the tubes. Weight of each tube is 45 kg.

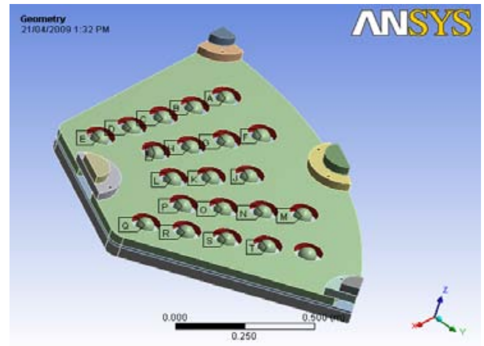


Figure 11 : Filter sheet with Considering Point mass

Figure 12 shows the four different point at which the Stress value is maximum near at the base support for the worst condition i.e. at Hydro test –without weight which is having maximum stress value among all the conditions considering the point mass.

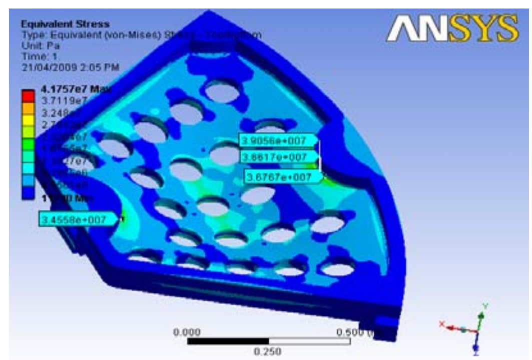


Figure 12 : Four points where stress value is maximum

Analyzed the 1/6th portion of Existing filter sheet having 21 holes for mesh size 15 mm. Following table shows Von mises stresses and Deformation value for without point mass and considering the mass of tubes(Each tube weight = 45 kg) for all seven conditions.

Table 2 : Stress & Deformation for Mesh size 15 mm

S.N	Conditions	Mesh size =15 mm = 0.015 m			
		Without Point Mass		With Point Mass	
		Von Mises Stress (Pa)	Deformation (m)	Von Mises Stress(Pa)	Deformation (m)
1	Self Weight	7.2964 e5	2.2804 e-6	5.2877 e6	1.8405 e-5
2	Differential Pressure-Without wt	1.6705 e7	5.1273 e-5	1.6705 e7	5.1273 e-5
3	Differential Pressure-With wt	1.5976 e7	4.8994 e-5	1.1419 e7	3.2932 e-5
4	Hydro test-Without wt	4.1757 e7	0.00012814	4.1757 e7	0.00012814

5	Hydro test-With wt	4.1028 e7	0.00012586	3.6472 e7	0.00010979
6	Back Pressure-Without wt	1.6682 e7	5.1288 e-5	1.6682 e7	5.1288 e-5
7	Back Pressure-With wt	1.7411e7	5.3569 e-5	2.197 e7	6.9675 e-5

IV. Experimental Validation

For all new product lines, initial Design should follow SOC-306.

All new product equipments shall be tested at 2.5 times the operating pressure using Hydro test. The Hydro test shall have slow built up of pressure, from base pressure to test pressure over a period of 120 min. The equipment shall be maintained at test pressure for 30 min. The pressure shall be gradually reduced to base pressure within a period of 45 min. After test, all components shall be subjected to NDT (Non Destructive Test), the following NDT shall be done-Visual Inspection-No surface irregularities must be present and Pre Dyed components should have no loss of dye due to leakage.

Ultra Sonic Testing–Post Test, internal damage shall get amplified if any, and shall be recorded in an Ultra Sonic Test. The test performance of the assembly should be completely elastic, this shall be verified by checking the dimensions of product for any permanent yield.

a) Hydro Test Condition

Working fluid - Water with Anti Scaling Additives
Test Pressure - 2.5 x 0.07 MPa

Leak Inspection -Sensors (LDR) on the top side of Filter Assembly.

Remark-Simultaneous testing of all 7 chambers was done. Filter holes were plugged with caps of SA 204.

b) Test Execution Details

Begin Time : 09.00 hr Base
Pressure : 0 MPa (Empty vessel)
Peak Pressure Time : 11.00 hrs
Peak Pressure : 0.175 MPa
Pressure relief begins Time : 11.30 hrs
LDR Warning : Zero
Pressure Drop Warning : Zero

Visual Inspection Details involved No leak observed on Top Side of Assembly, No visible damage observed after test and Plug Adhesion intact after test.

According to Auditors Remark,

1) Code requirements have been met by the analysis.
2) The Mesh is satisfactorily fine enough to generate accurate results.
3) The boundary conditions were inspected. The maximum Stress in Filter sheet is 32 MPa, however nominal value if calculated is much lower, it satisfy FOS is 5.
4) Gasket plate shows peak pressure of 34 MPa.however it is observed to significant stress raiser due to vicinity of contact and relatively less thickness of the plate compared to the other components.
5) Material Non Linearity may not be modeled in future analysis as it will have negligible effect on accuracy and unnecessary increases solution time.

V. Design Optimization

As we see there is chance for design optimization, we checked for two different optimizations, Shape optimization and Thickness optimization

a) Shape Optimization

For shape optimization we tried with increasing filter mounting holes. While increasing filter mounting holes we didn't violate minimum centre distance between two holes. We could increase holes from 21 to 28. For 28 holes we analyze the filter sheet assembly as shown in fig 13 with keeping same boundary conditions as were for 21 holes. We directly analyzed for the worst case.

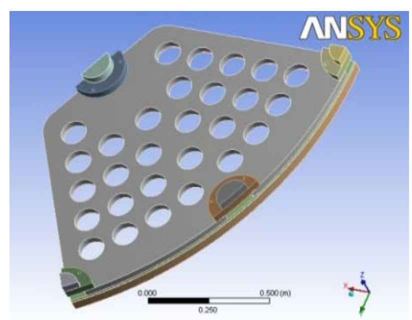


Figure 13 : Proposed Filter sheet model

Following are the results after solving proposed tube sheet having 28 holes for the worst condition with and without point mass with refined mesh size is taken as 15mm which shows that design is safe. Therefore shape can be optimized upto 28 holes. Max Equivalent stress = 4.2636 e7 Pa

Max. Deformation = 0.00014293 m

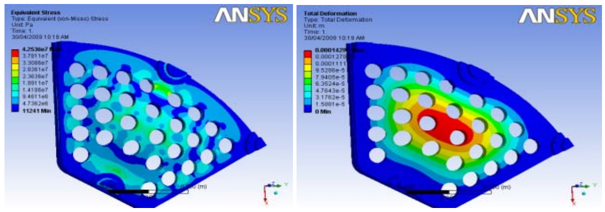


Figure 14 : Equivalent stress & max deformation for Hydro test without wt condition

b) Thickness Optimization

Following are the results after solving proposed tube sheet for shape and thickness optimization for the worst condition with and without point mass with refined mesh size is taken as 15mm.

Max Equivalent stress = 5.3959 e7 Pa
Max. Deformation = 0.00020162 m

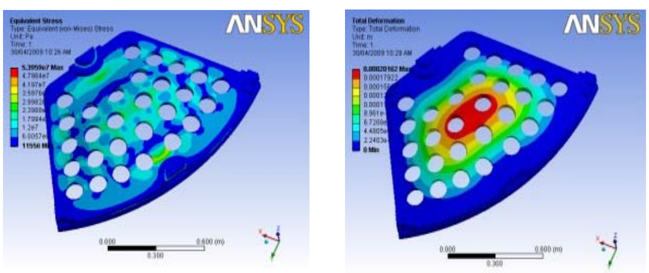
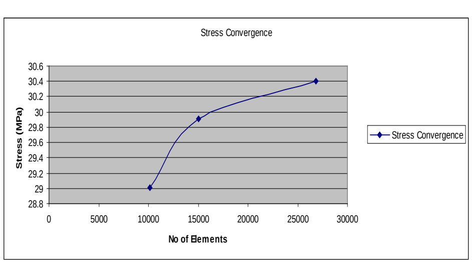


Figure 15 : Equivalent stress & max deformation for Hydro test without wt condition

VI. Mesh Sensitivity Analysis

Size of elements influences the convergence of the solution directly and hence it has to be chosen with care. If the size of elements is small, the final solution is expected to be more accurate. However, we have to remember that the use of elements of smaller size will also mean more computational time. As the number of elements increases, the size of each element must decrease, and consequently the accuracy of the model generally increases. Gasket plate having 12 mm thickness which is less as compared to others. The Gasket plate having contact on both sides Therefore there is not reliable stress concentration. Hence we should rely more on probe values as there is stress concentration.



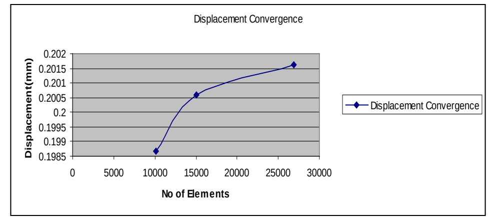


Figure 16 : Stress& Displacement Convergence

For shape & thickness optimization, the Stress and Displacement Convergence is as shown in figure 16 for worst condition. As the no of element goes on increasing corresponding stress and displacement goes on increasing. The above graph of obtained for any general finite element analysis shows how the accuracy of the analysis increases with increasing element numbers.

VII. Conclusion and Future Scope

a) Conclusion

Analysis results are reliable as seen in Mesh Sensitivity convergence and actual Testing. FEA Validation shows we can increase efficiency of Filter sheet by increasing number of tubes and still maintaining Factor of Safety 5.Thickness Optimization also indicates material saving and it is concluded that the optimized thickness and shape be sent for CFD analysis to check suitability.

b) Future Scope

Currently inlet to central plate is not designed. If such a inlet is designed then its structural analysis is recommended in the future. In such analysis, we will have to reassess the performance of peripheral shell.

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