Energy Audit of Vacuum System

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ABSTRACT

Vacuum pumps consume nearly 15-20% of total power required by a paper machine. Due to non-availability of published benchmarks, many mills are using much more power for vacuum generation than really required. By way of audit, it is possible to identify the points where there is a potential for energy conservation. The present work indicates how such an audit program may be conducted.

INTRODUCTION

Paper machine vacuum system is a highly power consuming area, requiring nearly 15% of total paper machine power requirement. In absence of sufficient information, it is often not possible to analyze the power audit of the vacuum system. As on today, many systems and audit procedures are available to evaluate and audit the vacuum pump for power consumption, but in this paper, the main emphasis has been given to minimize the vacuum requirement along with in-house testing of the vacuum pump.

With introduction of Energy Conservation Act, as well as increasing power and fuel costs day by day, it becomes necessary to minimize the power consumption in every process & equipment.

Typical Vacuum System

Typically, a vacuum system consists of vacuum pump, exhaust silencer, intake air water separator, vacuum piping, valves, and relevant instrumentation. Normally, several consumption points are connected to a single header, which is connected to water separator. From the top of separator, air is removed and fed to the vacuum pump, and from the bottom, process water is taken out using a centrifugal extraction pump.

There are several possibilities in a vacuum system resulting in power wastage-

a. There is a large pressure (vacuum) drop across the pipelines.
b. Vacuum control in different process sections is being done using the air-bleed technique, resulting in more power requirement.
c. Inadequate separator size resulting in process water carryover to vacuum pump, and hence increased power to pump that water out.
d. High seal water temperature resulting in seal water evaporation and thus increased load on vacuum pump, or decreased vacuum levels.
e. Inadequately sized exhaust separator and piping resulting in increased power consumption.
f. Scaling inside vacuum pump resulting in increased power.
g. Finally, much higher vacuum is being applied to process than that really required.

A brief description here is presented to elaborate on above points.

Vacuum Pump

The very first step is to evaluate the vacuum pump condition. If there is abnormal gap between the rotor and stator, the seal water requirement increases resulting in more power consumption to pump seal water, as well as possibility of leakage of air from exhaust side to inlet side. This can be done very easily during a shut, by running the vacuum with its suction valve closed and monitoring the inlet vacuum condition. Ideally, the absolute pressure at the inlet side should be equal to the vapor pressure of sealing water at operating temperature. A periodic evaluation of inlet absolute pressure this way can be done in order to know the health of the vacuum pump regarding leakage of vacuum from discharge side to suction side.

Piping

Second step is to evaluate the piping system. For the same, a water tube manometer is fitted in such a way that one side is connected to the application side, and other is connected to vacuum pump suction. This holds good for the piping where no valve is employed in between the lines. Alternatively, the valves in piping may be kept fully open. This gives the pressure drop across piping in mmWg. A high value indicates increased pressure drop in the piping system indicating need for increased pipe size to be used for the same.

While taking observations, it is necessary to check that all valves are fully open. A closed or partially open valve may result in a pressure drop much higher than the capacity of manometer, and as a result the manometer fluid (normally water) is carried away with air towards the vacuum pump side. In cases where it is doubtful to have an increased pressure drop across piping, it is advisable to use mercury in manometer, and if pressure drop is approximately known, then the case may be considered for water.

Air Bleed Control of Vacuum

Many a times, vacuum in different sections is controlled by allowing some amount of air to get into the vacuum piping directly. Due to increased amount of air in that particular section, pressure drop increases rapidly thus reducing the vacuum locally. This is more common in mills producing different varieties of paper in terms of quality and basis weight, and using a

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fixed set of vacuum pumps for all varieties. As GSM increases, air- flow through say wire part decreases resulting in more vacuum in the header. In cases, this may result in increased drag load on the wire part and to avoid tripping of wire part, some vacuum is released through a bleed valve.

When such a situation exists, it is a clear example of applying more power to vacuum pumps than required. In such a case, reducing rotational speed of vacuum pumps or installation of a smaller sized vacuum pump must be strongly considered.

Separator-Extraction Pump

In a typical case, the extraction pump installed on the separator was of much smaller size than required. This resulted in process water entering to vacuum pump. The plant final effluent was being taken to vacuum pump as seal water and after sealing it was allowed to drain. Electrician reported the problem of increased load on vacuum pump in some grades of paper. It was soon noticed that the process water was getting into the vacuum pump, and it was the cause of increased load. Increasing vacuum in Lo-Vac devices, increasing head box consistency solved the problem immediately.

To solve the problem permanently, without altering other parameters e.g. head box consistency (which may result in poor formation), installation of drop legs was considered. At first, 2 drop legs were installed providing a total drop length of 1.5m each. It was observed that these were extracting a lot of water, and process water ceased to get into vacuum pump.

Seal Water Temperature

Seal water temperature must be as low as practically possible. At elevated seal water temperatures clubbed with increased vacuum levels, a part of the seal water evaporation takes place. The vapors produced by the evaporated seal water result in increased load on vacuum pump thereby reducing the gauge vacuum.

In most practical cases, it is normally not feasible to cool down the sealing water. So, either fresh water or back water is used for sealing purpose. After sealing, the extracted water is supplied to other processes.

Application of More Vacuum than Desired

This is the most common type of practice resulting in increased power consumption in vacuum pump. In fact, most process applications are so complex in nature that development of relationship between power applied for vacuum generation and benefits obtained is virtually impossible. For example, let us say on a typical paper machine, there are six vacuum boxes. One can easily say that an increase in vacuum will result in dryer sheet after the couch. But that will, to certain extent, result in decreased press efficiency at the same press parameters. The steam consumption in dryer section may reduce, or remain constant; or even increase in a few situations. In this way, we can say that the change in steam consumption in dryer section is a function of vacuum in each box, machine speed, wire type, pulp properties, etc. As the development of exact correlation curves is very difficult, to be on the safer side towards production maximization, a papermaker tends to increase vacuum.

With increasing energy prices during past few years, this practice has been significantly reduced; and now-a-days, most papermakers try to minimize power consumption also. But due to non-availability of sufficient information on designing and optimization of complex vacuum systems, they find it difficult to achieve their goals.

Energy Audit Areas in Vacuum System

For energy auditing, following approach can be used as a primary guideline-

1. Check vacuum pump- capacity, leakage and performance.
2. Check piping system, percent opening of valves, pipe sizing, leakage etc.
3. Analyze actual vacuum requirements.
4. Analyze extraction system efficiency.

Checking Vacuum Pump

The capacity of vacuum pump primarily depends upon its mechanical design, type of impeller, rotational speed etc. But as the vacuum is increased, seal water evaporation rates increase rapidly adding quantity of air (vapours) to be handled. For a particular set of operating conditions, this results in drop in capacity in terms of vacuum obtained at the suction side of the pump.

For checking of pump, normally airflow at the exhaust side is measured. This measurement can either be based on orifice calibrated for the purpose of an anemometer. During the measurement, inlet and exhaust pressures are also measured and converted to absolute pressure. With this, the airflow capacity of a vacuum pump can be calculated as under-

Vacuum Pump Suction Vacuum = Ps inch Hg.
Vacuum Pump Suction Absolute Pressure = (29.92-Ps) inch Hg.

Vacuum Pump Exhaust Pressure = Pe inch Hg (Gauge)
Vacuum Pump Exhaust Pressure = (29.92+Pe) inch Hg (Absolute)

Exhaust airflow (measured) = Qe
Intake Airflow = Qe * (29.92+Pe) / (29.92-Ps)

It should be noted that the capacity is directly proportional to the rotational speed of the vacuum pump. Any increase or decrease in rotational speed should, therefore, be considered. As the pump becomes old, impeller wear, and/or deposits on impeller reduce volumetric capacity of pump. Now-a-days, improved metallurgy has allowed to run pumps for years without trouble, yet, checking the pump for volumetric capacity should be done periodically.

Having checked the pump for volumetric capacity, it should be checked for internal leakages etc. In water ring vacuum pump, though, this

Table-1: Power Consumption in Vacuum Pump

	A	B	C	D	E	F	G	H
1	Hq	Bar	Cum			KW/cum		
2	Vacuum	Pressure	Volume	Pdv	CUMUL.	Power		
3	30(1-D4)		1/b4	(b3+b4)* (c3-c4)2		96.1* 64.60		
4								
5	28.5	0.05	20.00					
6	27	0.1	10.00	0.75	2.32	3.80	Power	
7	25.5	0.15	5.67	0.42	1.91	3.12	Wasted	
8	24	0.2	5.00	0.29	1.61	2.64		
9	22.5	0.25	4.00	0.23	1.39	2.27		
10	21	0.3	3.33	0.18	1.21	1.97		
11	19.5	0.35	2.66	0.15	1.05	1.72		
12	18	0.4	2.50	0.13	0.92	1.50		
13	16.5	0.45	2.22	0.12	0.80	1.31		
14	15	0.5	2.00	0.11	0.69	1.13		
15	13.5	0.55	1.82	0.10	0.60	0.98		
16	12	0.6	1.67	0.09	0.51	0.84		Power
17	10.5	0.65	1.54	0.08	0.43	0.70		Actualy
18	9	0.7	1.43	0.07	0.36	0.58		Required
19	7.5	0.75	1.33	0.07	0.29	0.47		
20	6	0.8	1.25	0.06	0.22	0.37		
21	4.5	0.85	1.18	0.06	0.16	0.27		
22	3	0.9	1.11	0.06	0.11	0.17		
23	1.5	0.95	1.05	0.05	0.05	0.08		
24	0	1	1.00	0.05	0.00	0.00		
25	-1.5	1.05	0.55	0.00	0.00	0.00		
26						Total		
27						Power		
28						Consumed		
29								

problem is very less, yet, the pump must be periodically run and slowly the suction valve should be closed. This will result in increase of vacuum at the pump suction side. The lower the vacuum is, the more is leakage inside the pump. The reasons include leakage due to inadequate quantity of seal water, worn out impeller, worn out stator resulting in non-uniform film of seal water around impeller etc.

It is also possible to minimize leakages by increasing the quantity of seal water. But increased quantity of seal water means more power to provide seal water to vacuum pump, as well as more power required by the pump to extract this seal water out of the pump. In this way, monitoring of seal water flow rates can also be used as an indicator of health of vacuum pump.

Checking of Piping System

Vacuum piping system is another critical area that needs special attention. Both under and oversized pipelines harm the system from vacuum control and energy conservation point of view. In case the pipeline is undersized, it will result in increased pressure (or vacuum) drop across it, resulting in requirement of more increased vacuum at vacuum pimp inlet. At the same time, due to increased vacuum, the pump has to pump out more volume of air thereby increasing the power consumption drastically. This can be seen by table-1.

In the above table, we can see that by applying 22.5" vacuum in place of 15", we apply nearly double the power that is actually needed. In fact, due to the above reasons, many mills have installed VFD (Variable Frequency Drives) for vacuum pumps also.

To check the piping system, as indicated above, a differential pressure gauge, or a simpler form U-tube manometer is connected across the piping system at both ends. The manometer should be connected during a shut, as during operation all the fluid may get sucked off by the vacuum line to which one end of manometer is being connected. In a few cases, it has also been observed that during startup and shutdown mercury was sucked up by downstream line. This happens in case of shut off vacuum valve in piping, or due to sudden transients developed during shut down. Use of a longer manometer tube than desired just to note pressure drop is a must to safeguard against this.

In this way, pressure drop across pipeline can be noted and computed. We know as the vacuum increases, air gets rarified, and hence pressure drop would be less, yet it becomes more important to evaluate the same as at higher vacuum level as the higher the vacuum, the more pressure drop will cost in terms of energy consumption. In case significant pressure drop is obtained, analysis should be made to consider a next higher size of pipeline, considering cost benefits as well as the investment required.

It is not always necessarily beneficial to have larger pipelines. In case of much higher line sizes, the operation of vacuum control valves becomes difficult. For the same, we may consider that we want to control a 3/4"hosepipe flow using a 6" valve in the main line after which a hosepipe is connected just after a reducer. A slight opening of valve will immediately increase flow to maximum. In this way, oversized valves result in poor control allowing desired airflow with a partially open valve. Alternatively for such circumstances, vacuum control valve may be placed in lower diameter pipeline.

Gradually opening the valve and plotting vacuum obtained vs. percent valve opening can be done to check this. In case of oversized valve, vacuum generated will become nearly constant at a particular valve of opening much below 100%.

Vacuum leakages are generally much easier to identify due to whistling sound produced and hence can be attended much earlier, unlike compressed air leakages. A leakage results in increased airflow and hence increased load on vacuum system.

Branching in pipelines with a common header and distribution of vacuum to different sections is another critical area of analysis for vacuum system. Normally, a lot of consumption points are connected to a common header connected to a single vacuum pump. If, vacuum requirement of different sections are different, it implies that a high vacuum source is being used to feed a low vacuum requirement section. Paper machine wire section is a good example of the same. Initially, much lower vacuum is required by Lo-Vac devices, then in wet and dry suction boxes, gauge vacuum is increased gradually. Note that the same vacuum pump is feeding the suction boxes with maximum and minimum vacuum.

In such a case consideration should be made for a separate vacuum pump for low vacuum requirements. For very low vacuum centrifugal blowers may be used, while for moderate (6-8”) vacuum, roots blower can be easily installed. In some cases, paybacks of a couple of months have been observed for installation of a blower in place of vacuum pump.

Analysis of Actual Vacuum Requirements

Actual vacuum requirements can be calculated by models which give output consistency as a function of furnish type, type of fabric (wire/felt), type of suction box, inlet consistency, freeness of pulp used, etc. It is possible to get better sheet dryness after a particular section even with applying same or lower vacuum.

The methodology incorporates use of online consistency determination apparatus, and applying different vacuum levels at different suction boxes a vacuum versus output consistency database is prepared for a particular paper machine configuration and that particular quality of paper being made. With this data, using regression analysis, models are prepared to predict output consistency as a function of applied vacuum in a particular section. These models are then used for optimization of vacuum requirements for obtaining a particular output consistency.

In fact, output consistency after a suction box increases with increase in vacuum, but the increase is reduced as vacuum is increased. After a particular level increase in vacuum does not result in significant increase in consistency. In mills where online consistency measurement apparatus are not available, the following methodology can be adopted to optimize vacuum requirement to a certain extent.

In the wire part, vacuum must be in increasing order. For the same, last one or two suction boxes are closed, to see the effect of vacuum reduction on wire. In case of reduction in web consistency particularly on open draw machines, the draw becomes slack. At the same time, a tight draw means an increase in web consistency. If there is no significant effect on draw, it may be assumed easily that there is a possibility of vacuum reduction in wire part. Now, last suction box is opened as earlier, and the first suction box is kept slightly open. Now, other boxes are reduced in such a way that each suction box shows increased vacuum over the previous one. Care should be taken to ensure that the dry line remains in its place.

After dry line, it is often necessary to open valves much more to achieve desired vacuum. After edge cutter nozzle, target must be to stop as much as suction boxes as possible, with the last suction box full open. Having done that, one can clearly observe the difference between maximum vacuum in a suction box and vacuum at the inlet of vacuum pump. As indicated above, this difference can be minimized by reducing vacuum pump speed or by replacing vacuum pump with that of a lower capacity.

After reducing vacuum in the wire part, airflow measurement indicates total airflow by wet and dry suction boxes. It is possible to shut off all dry suction boxes, temporarily and maintain same vacuum in wet suction boxes by adjusting vacuum valves. At this stage, though paper is broken, web consistency up to dry line is same. Airflow measurement at this position reveals airflow needed by wet suction boxes. Since vacuum in wet suction boxes is normally very low, one can easily put a blower (centrifugal or roots) for wet suction boxes. After this a much lower rated vacuum pump can be used for dry suction boxes.

In some cases, it has been found that the vacuum power consumption in wire part was reduced to 20-40% of that running earlier. After power consumption in wire part vacuum was reduced, no adverse effect on paper machine dryer section steam consumption, or machine speed, or runnability was observed.

In fact, a reduction in wire part vacuum also resulted in reduced drive power in wire part, increased wire life, reduced wire marks on paper etc.

Analysis of Extraction System

The role of extraction system is to remove process water before it can enter the vacuum pump. Improperly designed extraction system results in increased load on vacuum pump in handling the process water, loss of process water thereby resulting in increased water consumption in the plant, fluctuations in vacuum generated etc.

On paper machines producing coloured grades, if process water enters vacuum pump, an appearance of seal water from vacuum pump exhaust silencer, to be of the same colour as that of process water indicates extraction system malfunctioning. There could be following reasons for extraction system malfunction-

1. Undersized extraction pump.
2. Significantly oversized extraction pump.
3. Vacuum much higher than suction head of extraction pump.
4. Gland leakages at extraction pump.
5. NRV failure in extraction piping.

In case of undersized extraction pump, obviously, water extraction would not be adequate and remaining water will first fill the separator tank, and then this will start entering vacuum pump. Similarly, in case of significantly oversized extraction pump, there is a possibility of air-locking of extraction pump. Installation of a circulation line from pump outlet to separator tank with NRV is done to avoid this problem. The condition of NRV in extraction pump outlet also plays a significant role in proper functioning of extraction pump. Gland leakages at extraction pump should also be considered in case of process water carryover beyond water separator.

In case of a running system, providing a controlled flow of water through some extra line, as well as increasing the vacuum in process points by shutting off some vacuum boxes etc, can be done to check the performance of extraction pump. If the extraction pump is working satisfactorily at a vacuum about 2” higher than maximum normally applied the pump may be considered satisfactory. In case extraction pump does not extract water at higher vacuum levels, it must be replaced with a suitable one.

Frequently switching On and Off the extra water supply to the separator at the increased vacuum level can be done to check the performance of NRV. In case of a defective NRV, the performance of extraction system will be perfect. If water carryover starts to vacuum pump during this study, this indicates that the NRV is not functioning well.

Approaches for Energy Conservation

It is possible to suggest suitable energy conservation scheme only after system audit. The suggestions may include modification in separator extraction pump piping, reduction in rotational speed of vacuum pump, replacement of vacuum pump with a smaller one or some different type one, changes in vacuum distribution etc. Depending upon the results and inferences from audit, and amount a mill is ready to spend initially, in some cases, it is possible to reduce pump speed in place of replacing the pump, and only after being satisfied of results obtained with this, one may opt for replacement of vacuum pump.

Fundamentally, for low gauge vacuum requirement, centrifugal blowers are the best. For relatively higher vacuum levels, lobe blower or roots blowers can be used. Due to absence of a sealing fluid such as water or oil, operation of lobe type blower becomes difficult due to back flushing of exhaust air from exhaust side to intake side through within the pump itself. In such a case, a water ring pump works better. In this way, selection of a vacuum pump must be based on requirement of gauge vacuum level in the process.

Drop legs (or barometric legs) are also installed at places to minimize load on extraction system. These provide a steady vacuum as well as reduce airflow requirement of vacuum pump just by controlling the vacuum. In case drop legs are not in operation, these should be used to maximize extent possible.

CONCLUSION

Audit and post audit activities to reduce power consumption in vacuum pumps yield significant gains. In some cases, it has been found that the power consumption could be reduced to nearly 40% of the same earlier.