SPECIFYING STEAM AND RATING CONDITIONS FOR SPECIAL PURPOSE STEAM TURBINES

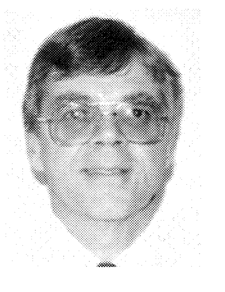
by

John S. Aalto

Manager of Application Engineering, Industrial and Power Systems

General Electric Company

Fitchburg, Massachusetts



John S. Aalto is Manager of Application Engineering for GE Industrial and Power Systems, General Electric Company, Fitchburg, Massachusetts. He has been engaged in all major aspects of rotating equipment design, development, and applications over the past 20 years. During this period, he has had application experience with steam turbines for TG Sets for U.S. Navy service, feed pump turbines for utility applications, steam turbines for land-based generator drive service, centrifugal compressors, and mechanical drive steam turbines for industrial and petrochemical applications. He has authored technical papers on steam turbines and centrifugal compressors.

Mr. Aalto received a B.S. degree in Mechanical Engineering from Northeastern University (1971).

ABSTRACT

The data required by turbine vendors to properly develop a design for a special purpose steam turbine are discussed in detail. Topics covered include discussion of continuous steam conditions, turbine power ratings and sizing, speed ranges, efficiency definition and calculation, guarantees, and purchaser evaluation criteria. It will be pointed out how specification of additional data during the proposal phase can result in a turbine design which more closely matches the actual requirements of the project.

Recommendations and proposals will be pointed out and then discussed in detail.

INTRODUCTION

The purpose herein is to try to define all of the design parameters that are required by a turbine designer during the proposal phase. The additional definitions proposed will augment the data usually found in customer specifications and API 612 data sheets. Where definitions in API 612 and NEMA SM-23 are not clear or are nonexistent, definitions are proposed that meet the unwritten intent of these documents. It will be demonstrated how a little bit of extra work during the specification of special purpose steam turbines can result in more consistent turbine proposals from different vendors and turbine designs which more closely match all the project requirements.

The turbine designer has many parameters to consider during the proposal design. The ones that have the most significant effect on the final design will be discussed in detail.

Recommendation

Supplementary data sheets (APPENDIX) are proposed which can be used by purchasers at the start of each project to specify the additional data suggested to prospective turbine vendors.

The supplementary data sheets can also be used to summarize and organize this additional data.

To reiterate, the purpose is to supplement the requirements and definitions of API 612 and NEMA SM-23, not to replace them.

CONTINUOUS STEAM CONDITIONS

The continuous steam conditions that are specified by the purchaser probably have a bigger effect on the turbine design than any other single parameter. Abnormal steam conditions that occur infrequently and with short duration need to be considered separately from continuous ones.

Recommendation

New definitions "maximum continuous" and "minimum continuous" are proposed. Operation at these steam conditions can be 100 percent of the time. "Continuous" replaces "shall average" from NEMA SM-23. New definitions clear up ambiguity between definitions in API 612 and NEMA SM-23. Definitions for maximum and minimum continuous extraction pressure, admission pressure, admission temperature, and condensing exhaust pressure are proposed, since NEMA SM-23 does not address them. It is proposed that pressure "swings" be based upon gage pressure. A modification to "swings" on noncondensing exhaust pressure is proposed. Proposed default values for all steam parameters are indicated in Table 1, and can be specified on the supplementary data sheet. Actual values should be used instead of default values if available.

Table 1. Default Values for Continuous Steam Conditions for Mechanical Design.

	Inlet Pressure	*Inlet Temperature*	*Extraction Pressure*	*Exhaust Pressure Non-Condensing*	*Exhaust Pressure Condensing*	*Admission Pressure*	*Admission Temperature*
Maximum Continuous	Normal × 1.05	Normal + 15 F	Normal × 1.1 or + 10 psi	Normal × 1.1 or + 10 psi	Normal + 1.0" HgA	Normal × 1.05	Normal + 15 F
Normal	Customer Specified	Customer Specified	Customer Specified	Customer Specified	Customer Specified	Customer Specified	Customer Specified
Minimum Continuous	Normal	Normal	Normal × 0.8 or − 10 psi	Normal × 0.8 or − 10 psi	0.5" HgA	Normal	Normal

When the continuous steam condition requirements of API 612 and NEMA SM-23 are carefully studied and compared, there are ambiguities which can use additional clarification.

NEMA SM-23 discusses normal, maximum, and minimum steam conditions along with variations in steam conditions. It allows turbine "average inlet pressure of 105 percent of maximum inlet steam pressure." It also allows operation at maximum inlet temperature plus 15°F, as long as the "inlet steam temperature shall average not more than maximum temperature over any 12-month operating period."

Turbine mechanical designers must consider the amount of time that the turbine may be subjected to any specified steam condition.

If the turbine can operate for half its life at a certain pressure or temperature while maintaining a specified average, this pressure or temperature must be considered normal and continuous by the mechanical designer. To clarify terminology, instead of indicating that operation at some maximum plus five percent or plus 15°F is allowed, it is proposed that the pressure or temperature plus the allowable "swing" be defined as maximum continuous.

A simple example will help to explain. A plant has steam conditions of 600 psig and 750°F. NEMA SM-23 would allow operation to average 600 psig and average 750°F. While maintaining this average, operation at 630 (600 × 1.05) psig and 765 (750 + 15)°F is allowed; however, operation at lower than 600 psig and lower than 750°F is required to maintain the average. The proposed new definition of maximum continuous would allow continuous operation at 630 psig and 765°F, recognizing the fact that the equipment must be designed for these conditions continuously anyway.

In a similar manner, NEMA SM-23 allows operation with an average noncondensing exhaust pressure 10 percent above and 20 percent below maximum exhaust pressure. For mechanical design purposes, these swings must be considered as continuous operating conditions.

NEMA SM-23 does not recommend any specific allowable "swings" for admission/induction pressure or temperature, extraction pressure, or condensing exhaust pressure. (From this point on, the word admission will be used with the same meaning as induction.)

API 612 lists NEMA SM-23 as a "Referenced Publication" and requires "operation with variations from rated steam conditions per NEMA SM-23." It does not, however, define rated steam conditions. API 612 further states, "Maximum inlet pressure and temperature refer to the highest inlet steam pressure and temperature conditions at which the turbine is required to operate continuously." It does not, however, indicate whether this maximum pressure and temperature include the five percent pressure margin and/or the 15°F temperature margin noted in NEMA SM-23.

The special purpose steam turbine data sheets included in API 612 allow purchaser specification of minimum, normal, and maximum steam conditions. However, once again, they do not correlate back to NEMA SM-23 and also do not specifically indicate for what these steam conditions should be used. It should be pointed out that continuous steam conditions for sizing of steam turbines may (and probably should) be different from those used for mechanical design considerations. Steam conditions for turbine sizing will later be discussed in detail.

NEMA SM-23 does not specifically state whether pressure variations indicated are from gage or absolute pressure. It is proposed that all pressure variations be based upon gage pressure except for condensing exhaust pressure, which will be based upon absolute pressure.

Default values for continuous steam conditions to be used for mechanical design are proposed in Table 1. Maximum and minimum continuous values include margins required by NEMA SM-23. Normal values will be those which are expected during normal operation and must be specified by the purchaser. For cases where NEMA SM-23 has not suggested allowable variations for certain parameters, proposed values are indicated here. Using NEMA SM-23 as a guide, admissions are treated as inlets, and extractions are treated as noncondensing exhausts.

For normal extraction or noncondensing exhaust pressures below 100 psig, an additional default rule is proposed. A margin of 10 psi variation above normal in lieu of 10 percent will be used. In addition, for normal extraction or noncondensing exhaust pressures below 50 psig, an additional default rule is proposed. A margin of 10 psi variation below normal in lieu of 20 percent will be used; however, the minimum continuous exhaust pressure will never be less than atmospheric. These additional default rules recognize normal variations in steam header pressures in many plants.

For condensing exhausts, a nominal 1.0 in HgA increase in pressure is proposed to recognize normal cooling water variations. A minimum condensing exhaust pressure of 0.5 in HgA is proposed. This pressure, although extremely low, will ensure that turbine last stages will be suitable for maximum loadings in the event of unexpectedly cold cooling water.

Steam admissions are treated the same as an initial inlet. Wide variations in admission temperature can be extremely important to the turbine designer. Admission temperatures that are significantly different from the "through flow" temperature require special design consideration. "Wet" steam at the admission requires very special attention. These conditions must be made known during the proposal phase if they are anticipated.

The turbine mechanical designer must ensure that the turbine will be suitable for continuous operation at these conditions, independent of any other design parameters such as flow or power. Each pertinent parameter should be specified by the purchaser during the proposal phase unless the default values indicated will cover all expected "swings."

Since it is difficult for the purchaser to predict with certainty which combinations of continuous pressure and temperature will or can occur simultaneously, the turbine designer must assume that any combination of steam conditions is possible continuously, and account for these conditions in the turbine design.

These continuous steam conditions will be used by the mechanical designer for numerous purposes. Material selection of the turbine main components and casing design pressure and temperature are the most obvious. Each turbine vendor has hardware and material limits which are solely dependent upon continuous steam conditions. A maximum continuous temperature of 785°F, for example, could cause a turbine designer to use alloy steel for turbine inlet parts in lieu of carbon steel, resulting in a significant increase in cost of the turbine. If, in actuality, temperatures over 775°F are not envisioned, this must be pointed out to the turbine designer.

The possible combinations of continuous steam conditions are also very important during calculation of maximum bucket stresses. Maximum continuous temperatures determine the type of blade attachment to the turbine wheel, and variations in pressure are used to determine maximum stage loadings for calculation of bucket stresses and maximum unbalance pressures for diaphragm design. The entire turbine design must be suitable for continuous operation at these conditions. It can be pointed out that the designer of the piping to, and piping/exhaust duct from, the steam turbine should also consider these same aspects of steam condition variation.

Abnormal steam conditions (those which occur only intermittently) are also important to consider during the mechanical design of the turbine. It is suggested that the abnormal variations discussed in NEMA SM-23 for inlet pressure and temperature be accounted for in the design as a standard. Other abnormal variations in steam conditions must be made known to the turbine designers to allow proper design consideration.

The default values of the steam condition variation proposed here should only be used if the purchaser has not determined expected actual variations. Actual values will result in a less conservative, but still technically suitable design. In any event, either default or actual values should be indicated on the supplementary data sheet to the turbine vendors during the proposal phase.

TURBINE POWER RATING

Steam turbines designed to API 612 can drive many types of rotating equipment, including pumps, fans, blowers, generators, axial compressors, and centrifugal compressors. For the purpose here, the requirements of API 617 will be used as the basis for definition of turbine power ratings.

Recommendation

New definitions and default values for continuous powers for mechanical design are proposed in Table 2. New definitions clear up ambiguity between API 617, API 612, and NEMA SM-23. Turbine rated power includes 10 percent power margin per API 617. Minimum power is proposed as compressor normal × 0.8, since it was previously undefined. It is proposed that compressor rated point be defined as the point with the "highest power," not the "highest capacity." Actual values should be used instead of default values if available.

Table 2. Default Values for Continuous Powers for Mechanical Design.

Point	*Power*
Turbine Rated	Compressor Rated × 1.1
Compressor Rated	Customer Specified
Compressor Normal	Customer Specified
Minimum	Compressor Normal × 0.8

API 617 Centrifugal Compressors for General Refinery Service states, "Steam turbine drivers shall be sized to deliver continuously 110 percent of the maximum power (including gear, fluid coupling, or other losses, as applicable) required for the purchaser's specified conditions while operating at a corresponding speed with the specified steam conditions."

API 612 states, "Rated applies to the greatest turbine power specified and the corresponding speed. It includes all the power margins required by the specifications of the driven equipment."

NEMA SM-23 states, "Rated power is the maximum specified power output of the turbine."

For the expected operating points of any centrifugal compressor, the point requiring maximum power may not be coincident with the point requiring maximum speed. In this event, a design point defined as the "compressor rated point" with maximum required power and speed is specified. The turbine power rating is based upon the "compressor rated point." It should be pointed out that the "compressor rated point" defined here may not be the same as that defined in API 617, where a point with maximum speed and "at the highest capacity of any specified operating point" is used. The compressor operating point with the "highest capacity" will not necessarily have the highest required power.

The important point to make here is to ensure that the 10 percent margin specified in API 617 be added to the "compressor rated power" to determine "turbine rated power."

The minimum required power of any compressor operating point by itself is not important. What is important, however, is the required torque characteristic of the compressor at speeds and powers less than maximum. All expected operating points of the compressor should be reviewed and made available to the turbine designer because the maximum torque required from the steam turbine driver will not necessarily be at maximum power or speed, depending upon the process and gas conditions encountered by the centrifugal compressor. Minimum power will be discussed further with minimum speed.

A summary of default values for continuous powers for mechanical design is given in Table 2. Actual data should be provided on the supplementary data sheet if available.

TURBINE SPEED RANGE

API 617 states, "One hundred percent speed is the highest speed required for any specified operating point above the normal speed curve. If there are no specified operating points that require greater than normal speed, the 100 percent speed shall be the normal speed."

NEMA SM-23 states, "Rated speed is the speed corresponding to rated power."

API 612 states, "Maximum continuous speed (in revolutions per minute) is the speed at least equal to 105 percent of the highest speed required by any of the specified operating conditions." API 617 has a similar definition for maximum continuous speed. NEMA SM-23, however, states, "Maximum continuous speed is the highest specified operating speed. It is equal to or greater than rated speed."

Recommendation

New definitions and default values for continuous speeds for mechanical design are proposed in Table 3. New definitions clear up ambiguity between definitions in API 617, API 612, and NEMA SM-23. Maximum continuous speed is per API 612. Default minimum speed is proposed since it was previously undefined.

Table 3. Default Values for Continuous Speeds for Mechanical Design.

Point	*Speed*
Maximum Continuous	105%
100%	Customer Specified
Normal	Customer Specified
Minimum	80% *

*or actual point × 0.95

The minimum continuous operating speed of the turbine is much more important than the minimum power required. NEMA SM-23 does not address it. API 612 states that the turbine shall be capable of "Continuous operation at the lowest speed at which maximum torque is required with minimum inlet and maximum exhaust conditions. The purchaser will specify both the speed and torque values required." API 617 does not specify how to determine minimum continuous speed, but states, "Minimum allowable speed (in revolutions per minute) is the lowest speed at which the manufacturer's design will permit continuous operation," which is a result of the design, not a requirement of it.

The important consideration to keep in mind when specifying a minimum continuous speed is to be sure it is low enough to be below any specified operating points with a small amount of margin, but not with excess margin that will cause undue overdesign of the turbine buckets and rotor. The overall speed range, from maximum continuous to minimum continuous, is used when calculating bucket vibratory stresses and rotordynamics.

As noted above in the reference to API 612, the turbine must be designed for maximum torque down to minimum continuous speed. This is very important when calculating control stage power loadings due to the increase in energy on them at lower turbine flows.

It is proposed that the minimum continuous speed be defined as the lower of:

- 80 percent of 100 percent turbine speed
- Five percent below the actual speed of any required continuous operating point
- A speed specified by the purchaser

For the case when the 80 percent default value is used, minimum power will be set at 80 percent, resulting in maximum torque at minimum continuous speed.

Proposed default values for continuous speeds for mechanical design are indicated in Table 3. Maximum continuous speed will be based upon API 612 and 617, 100 percent turbine speed is the same as 100 percent compressor speed, and the normal speed of the compressor and turbine may be less than or equal to 100 percent speed. Minimum is as described above. Actual values of speed should be provided if available.

TURBINE SIZING

Determining required flow passing capability to ensure power margin for straight through turbines (no extractions or admissions) is relatively straightforward. Trying to ensure adequate power margin for the whole turbine and flow passing capability for each section of extraction or admission turbines is more complicated. These two turbine types will be discussed separately.

API and NEMA touch upon turbine sizing but further clarification is in order.

NEMA SM-23 states, "Minimum steam conditions are the lowest inlet steam pressure and temperature and corresponding exhaust pressure at which the turbine produces rated power and speed."

API 612 requires that turbines be capable of "delivering rated power at its corresponding speed with coincident minimum inlet and maximum exhaust conditions as specified on the data sheets." API 612 also recognizes that "to prevent oversizing and/or to obtain higher operating efficiency, it may be desirable to limit maximum turbine capability by specifying normal power or a selected percentage of rated power instead of rated power at the conditions specified."

Translated, this means that the more capability margin that is included in the turbine design beyond what is required at the normal operating point, the lower the efficiency will be at the normal operating point.

Adequate capability margin is absolutely essential. Excess capability margin will result in reduced efficiency during normal operation over the entire life of the turbine and may increase the initial capital cost of the turbine as well.

Straight Through Turbines

Sizing (flow passing capability) for straight through turbines will first be addressed. Parameters requiring definition are inlet and exhaust steam conditions, required turbine power, and speed.

Recommendation

Proposed default values for straight through turbine sizing parameters are indicated in Table 4. The worst case scenario for each parameter is default value. Margin at both 105 percent and 100 percent speed is proposed. To prevent oversizing, purchaser should specify conditions other than default values if available.

The continuous steam conditions discussed earlier are not necessarily the ones that should be used to size the turbine. When determining the steam conditions for sizing, the purchaser should consider each steam parameter separately and determine which extremes can occur simultaneously and what the power requirements of the driven equipment might be at that particular time. Depending upon the particular turbine design, turbine flow passing capability can vary with turbine speed; therefore, the turbine designer should ensure flow passing capability at both 100 percent and turbine maximum continuous speeds. The most conservative approach for straight through turbines is indicated in Table 4.

Table 4. Default Sizing Criteria for Straight Through Turbines.

Minimum Continuous Inlet Pressure
Minimum Continuous Inlet Temperature
Maximum Continuous Exhaust Pressure
Turbine Rated Power
100% Speed and
Maximum Continuous Speed

It should be noted that maximum continuous inlet temperature is used when sizing the turbine for a maximum flow instead of a power, not minimum continuous. If a maximum flow is specified instead of a power, an account must be made of the increased volume of the steam at the higher temperature.

Extraction or Admission Turbines

Both API 612 and NEMA SM-23 require only that the turbine be capable of rated power during operation at minimum steam conditions, with no mention of allowable variation in extraction or admission flows to reach rated power other than "Turbines shall be capable of continuous operation at conditions agreed upon between the purchaser and the vendor for extraction or induction or both" stated in API 612. When not discussed prior to the design of the turbine, each vendor can interpret these requirements to best fit his needs, which may or may not meet the needs of the purchaser. Is reduction in extraction flow, as the route to developing rated power, acceptable to the proposed process? If not, additional purchaser definition of turbine operating characteristics is required.

Recommendation

API-612 and NEMA SM-23 do not adequately address sizing of extraction or admission turbines. For extraction and admission turbines, it is proposed that each turbine section will be sized to pass a "flow," and the entire turbine will then be checked for power capability. Unless specified otherwise by the purchaser, it is proposed that reduction in extraction flow or increase in admission flow is the proper route to attaining turbine rated "power."

For extraction or admission turbines, to ensure power capability of the entire turbine, the flow passing capability of each turbine section must be adequate. Flow passing capability must be considered on a section by section basis. Power margin, on the other hand, is a result of the mode of operation of the entire turbine. A consistent approach that can be used for sizing these types of turbines, and that will ensure that the turbine sizing will match the purchaser requirements, will now be proposed. Only single automatic extraction or admission turbines will be discussed here, although the approach can be applied for additional turbine sections.

Extraction Turbines

For extraction turbines, there are three variables associated with each operating point that determine the approach required to size the turbine—throttle flow, extraction flow, and power. The purchaser specifies two of the three parameters, and the result of the design is the value of the third parameter. There are two basic cases which determine the design approach for these types of turbines: Maximum throttle flow specified and extraction flow is the result, and required extraction flow is specified and throttle flow is the result. In all instances, it shall be assumed that minimum steam conditions (Table 5) will be used unless specified differently by the purchaser.

Table 5. Default Sizing Criteria for Single Automatic Extraction Turbines.

Minimum Continuous Inlet Pressure	(3)
Maximum Continuous Inlet Temperature	(3)
Maximum Continuous Extraction Pressure	(1)
Minimum Continuous Extraction Pressure	(2)
Maximum Continuous Exhaust Pressure	
Turbine Rated Power	
100% Speed and	
Maximum Continuous Speed	

(1) used when sizing HP section
(2) used when sizing LP section
(3) normal inlet conditions used for HP section when determining extraction conditions for LP section sizing

Recommendation

Proposed default values for single automatic extraction turbine sizing parameters are indicated in Table 5. The worst case scenario for each parameter is default value. Maximum inlet temperature is proposed as part of minimum inlet steam conditions (not min). The use of normal inlet steam conditions to turbine high pressure section when sizing low pressure section is proposed. Flow and power margin at both 105 percent and 100 percent speed is proposed. To prevent oversizing, the purchaser should specify conditions other than default values, if appropriate.

As an aside, during purchaser specification of extraction or admission turbines, the specific quantity, or the range in quantity of required extraction or admission flow for each specified compressor operating point, should be determined, and this data should be made available to the turbine vendors. This process can help to uncover all required variations, some of which may be important to the sizing of the turbine.

There are some special cases where the high pressure section and/or the low pressure sections of extraction turbines must be sized at a startup condition and not holding extraction pressure. This is a special case which will not be addressed.

Herein, HP will be used as an abbreviation for high pressure, and LP will be used for low pressure.

Single Automatic Extraction Turbine Case 1 (Figure 1)

- Maximum throttle flow specified
- Normal and rated powers specified
- Turbine LP section "sized" by:

1. Customer specified operating point with maximum LP section flow, or

2. Specified maximum LP section flow, or

3. LP flow required for rated power at maximum throttle flow (used only if 1 and 2 are not specified).

- Extraction flow is the result

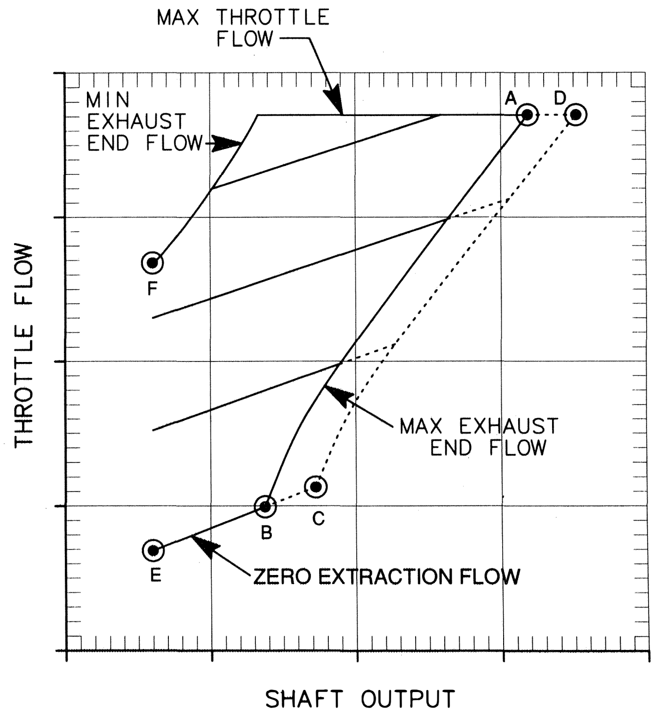


Figure 1. Extraction Map, Case 1.

Step A. Turbine HP section will be sized to pass maximum specified throttle flow at minimum inlet pressure, maximum inlet temperature, and maximum extraction pressure.

Step B. Turbine LP section will be sized to pass the flow from 1 or 2 above. (The required flow for 1 above will be determined with normal steam conditions and while holding extraction pressure.) The LP section will be sized to pass this required flow at minimum extraction pressure and maximum exhaust pressure and the temperature at the extraction resulting from running maximum LP section flow through the HP section at normal inlet steam conditions and minimum extraction pressure.

Step C. At normal steam conditions, the HP section design from Step A will be run with the LP section design from Step B. If, at maximum HP section flow and maximum LP section flow (Point A on Figure 1), the power developed is at least equal to turbine rated power, the design is complete and acceptable. The map will be cut off with a vertical line from maximum throttle flow to maximum exhaust end flow at rated turbine power. If, however, the resulting power is less than turbine rated, the LP section flow passing capability must be increased (from Point B to Point C on Figure 1) above what was required in Step B (above) until turbine rated power is developed (Point D on Figure 1).

It can be noted that even though the LP section flow at Points C and D is the same, Point C is used for LP sizing due to the higher temperature and, therefore, higher steam volume at the extraction.

Single Automatic Extraction Turbine Case 2 (Figure 2)

- Maximum throttle flow to be determined
- Rated power specified
- Turbine LP section "sized" by:

1. Customer specified operating point with maximum LP section flow, or

2. Specified maximum LP section flow, or

3. LP flow required for rated power at maximum throttle flow (used only if 1 and 2 are not specified).

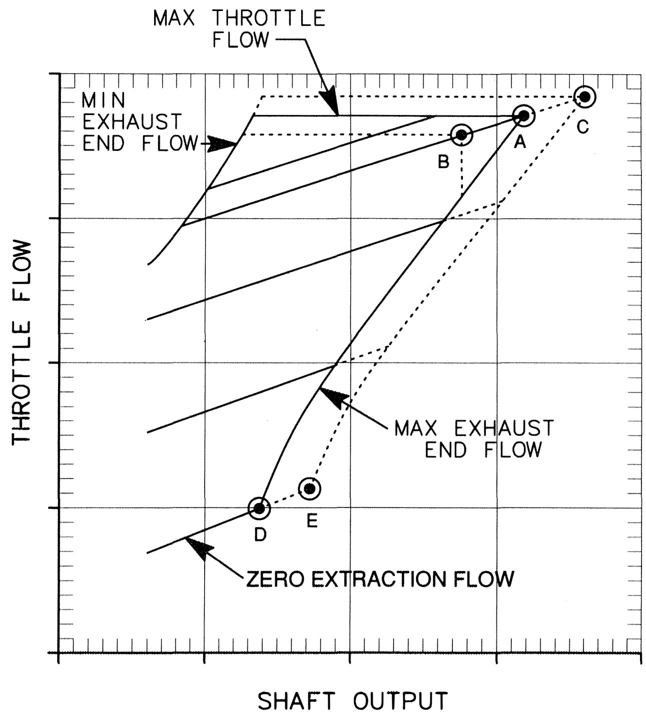


Figure 2. Extraction Map, Case 2.

- Extraction flow at normal power specified

Step A. Turbine HP section will be sized to pass the sum of the specified extraction flow plus the maximum LP section flow. (For the first iteration, a guess of the LP section flow may be required.) Minimum inlet pressure, maximum inlet temperature, and maximum extraction pressure will be used for sizing.

Step B. Turbine LP section will be sized per Step B of Case 1 above.

Step C. At normal steam conditions, the HP section design from Step A will be run with the LP section design from Step B. There are two possibilities:

Step D1. If, at maximum HP section flow and maximum LP section flow (Point A on Figure 2), the power developed is greater than rated power, the HP section maximum flow can be decreased (from Point A to Point B in Figure 2, maintaining constant extraction flow) until rated power is developed.

Step D2. If, however, the resulting power is less than turbine rated, both the HP section and LP section flow passing capabilities must be increased (from Point A to Point C for the HP section, and from Point D to Point E for the LP section in Figure 2), until rated power is developed at the specified extraction flow.

In summary, for extraction turbines, at minimum steam conditions, the HP section is sized at the uppermost right point of the extraction map and the LP section at the lowermost right.

Admission Turbines

As with extraction turbines, there are three variables associated with each operating point that determine the approach required to size an admission turbine—throttle flow, admission flow, and power. The purchaser specifies two of the three parameters, and the result of the design is the value of the third parameter. There are two basic cases which determine the design approach for these types of turbines: Maximum throttle flow specified and admission flow is the result, and admission flow is specified and maximum throttle flow is to be determined. Once again, it shall be assumed that minimum steam conditions (Table 6) will be used unless specified differently by the purchaser.

Table 6. Default Sizing Criteria for Single Automatic Admission Turbines.

Minimum Continuous Inlet Pressure	(3)
Maximum Continuous Inlet Temperature	(3)
Maximum Continuous Admission Pressure	(1)
Minimum Continuous Admission Pressure	(2)
Maximum Continuous Admission Temperature	(2)
Maximum Continuous Exhaust Pressure	
Turbine Rated Power	
100% Speed and	
Maximum Continuous Speed	

(1) used when sizing HP section
(2) used when sizing LP section
(3) normal inlet conditions used for HP section when determining admission conditions for LP section sizing

Recommendation

Proposed default values for single automatic admission turbine sizing parameters are indicated in Table 5. The worst case scenario for each parameter is default value. Maximum inlet temperature is proposed as part of minimum inlet steam conditions (not min). The use of normal inlet steam conditions to turbine HP section when sizing LP section is proposed. Flow and power margin at both 105 percent and 100 percent speed is proposed. To prevent oversizing, the purchaser should specify conditions other than default values, if appropriate.

Single Automatic Admission Turbine Case 1 (Figure 3)

- Maximum throttle flow specified
- Normal and rated powers specified
- Turbine LP section "sized" by:

1. Customer specified operating point with maximum LP section flow, or
2. Specified maximum LP section flow, or
3. LP flow required for rated power at maximum throttle flow (used only if 1 and 2 are not specified).

- Admission flow is the result

Step A. Turbine HP section will be sized to pass maximum specified throttle flow at minimum inlet pressure, maximum inlet temperature, and maximum admission pressure.

Step B. For the first iteration, the turbine LP section will be sized to pass the sum of maximum throttle flow plus maximum admission flow from 1 or 2 above. The LP section will be sized to pass this flow at minimum admission pressure, maximum admission temperature, and maximum exhaust pressure. The temperature (enthalpy) at the admission, resulting from running maximum throttle flow at normal inlet steam conditions and minimum admission pressure, will be used when "mixing" the admission steam with the throttle flow.

Step C. At normal steam conditions, the HP section design from Step A will be run with the LP section design from Step B. There are two possibilities:

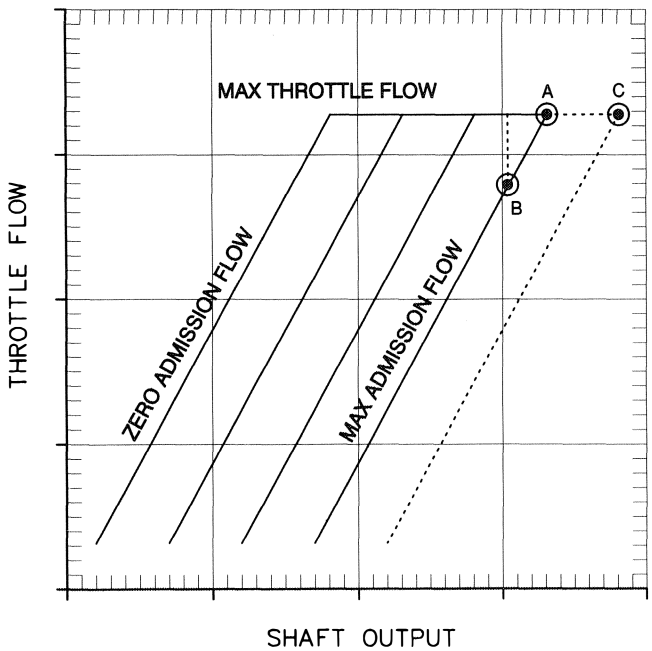


Figure 3. Admission Map, Case 1.

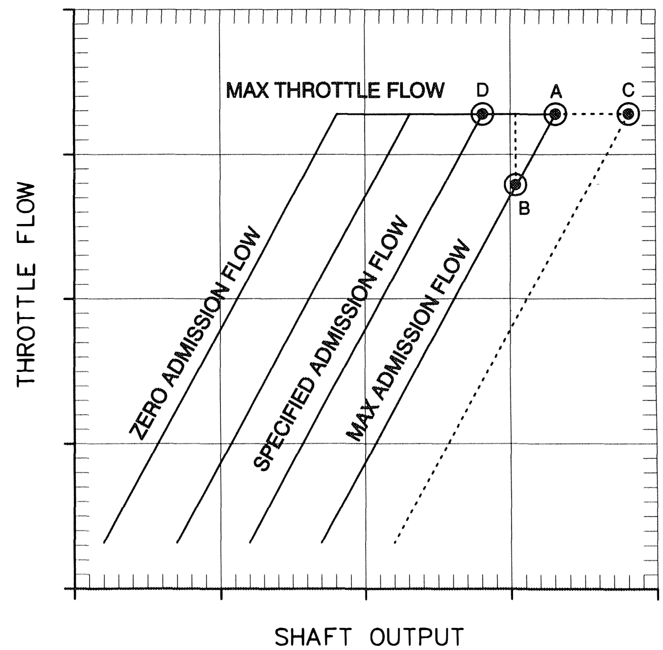


Figure 4. Admission Map, Case 2.

Step D1. If, at maximum flow through each section, the resulting power is greater than rated, the LP section sizing point is changed from Point A to Point B in Figure 3. Step B above will be repeated with the reduced throttle flow from Point B in Figure 3.

Step D2. If, at maximum flow through each section, the resulting power is less than rated, additional admission steam is required, and the LP section sizing point is changed from Point A to Point C in Figure 3 until rated power is developed.

Single Automatic Admission Turbine Case 2 (Figure 4)

- Maximum throttle flow to be determined
- Rated power specified
- Turbine LP section "sized" by:

1. Customer specified operating point with maximum LP section flow, or
2. Specified maximum LP section flow, or
3. LP flow required for rated power at maximum throttle flow (used only if 1 and 2 are not specified).

- Admission flow at normal power specified

Step A. Turbine HP section will be sized to pass the throttle flow required at the required operating point. (For the first iteration, this will be a guess.) The HP section will be sized at minimum inlet pressure, maximum inlet temperature, and maximum admission pressure.

Step B. The turbine LP section will be sized to pass the sum of the throttle flow from Step A plus the specified admission flow. The LP section will be sized to pass this flow at minimum admission pressure, maximum admission temperature, and maximum exhaust pressure. The temperature (enthalpy) at the admission, resulting from running the throttle flow from Step A at normal inlet steam conditions and minimum admission pressure, will be used when "mixing" the admission steam with the throttle flow.

Step C. The throttle flow in Step A should be iterated until the power that results from running the flow from Step A through the HP section and the flow from Step B through the LP section is equal to normal power (Point D on Figure 4). This becomes the maximum throttle flow, and the design procedure becomes the same as for Admission Turbine Case 1 above, Steps A, B, C, and D.

Extraction or Admission Turbine Sizing Summary

The important fact to remember when sizing extraction or admission turbines is that each section of the turbine should be sized for a flow at minimum steam conditions. When the turbine sections have been sized, the total turbine is checked for power margin and the turbine sections resized, as appropriate, if required.

Although not specifically associated with turbine sizing, for multisection turbines, minimum section flows can be important during turbine design. Turbine sections require minimum flows (the absolute value of the minimum flow will vary, depending upon steam conditions and turbine speed) to keep them cool. Operation at Point E in Figure 1, for example, is a case where the turbine is operating near maximum LP section flow, but at considerably less than maximum HP section flow. If the throttle flow at Point E is 25 percent of maximum, for example, the efficiency of the HP section at this flow may be very low or even negative! For the LP section, Point F in Figure 1 is an operating point that is functioning at considerably less than LP section design flow, and at some fraction of HP section design flow. Operation at small percentages of design flows results in high temperatures (or requires limits in operating flexibility), which must be considered during the turbine design. If operation at "off-design" points such as these are contemplated, the turbine designer must be made aware of this possibility during the design phase.

Turbine Vendor Margin

During the manufacture of steam turbines, each vendor has tolerances on the dimensions and flow coefficients of the inlet parts that control the flow passing capability of each section of the turbine.

Recommendation

Propose a five percent flow margin be included in the design beyond what is guaranteed to the purchaser.

To ensure that the "as manufactured" turbine does, in fact, have the flow passing capabilities discussed above, it is proposed that the turbine be designed with five percent additional flow margin above the guaranteed flow passing capability at the specified conditions. This is really the turbine vendor's margin, not the purchaser's. However, it is important to have. Assuming normal tolerances, five percent flow margin will assure that the expected flow passing capability is attainable.

SIZING EXAMPLE

What oversizing can mean to turbine performance is shown in Figure 5. It indicates the loss in available energy of steam for a given turbine section due to one percent throttling of the steam at the turbine inlet. An inlet throttling loss curve for a typical turbine design is shown in Figure 6. The more margin that has been included in the design beyond the normal operating point, the more throttling; therefore, more loss in available energy.

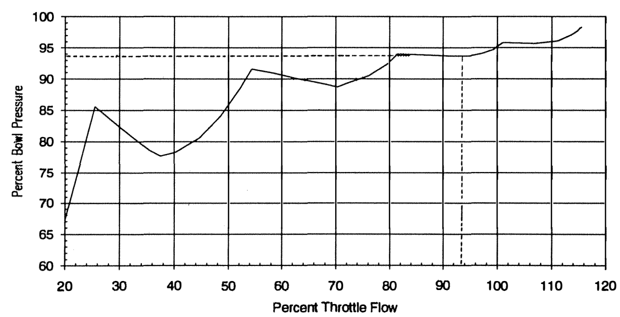


Figure 5. Percent Bowl Pressure vs *Percent Flow.*

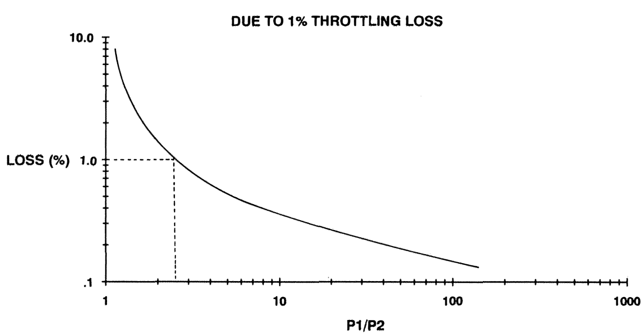


Figure 6. Loss in Available Energy Due to One Percent Throttling Loss.

A simple example will illustrate. Assume a noncondensing turbine with inlet conditions of 1500 psia/950°F and exhaust pressure of 600 psia. The section pressure ratio is therefore 2.50 (1500/600 = 2.5). It is shown in Figure 5 that for a pressure ratio of 2.5, the loss in available energy due to one percent throttling at the inlet is about 1.0 percent.

Assume that, using only normal steam conditions, 10 percent API hp margin and five percent flow passing margin are included in the base design, resulting in a maximum design flow of 115.5 percent (110.0 × 1.05 = 115.5).

Figure 6 is used to determine the actual amount of throttling. It is a typical curve of percent bowl pressure *vs* percent design flow. At 100 percent flow, the bowl pressure is 95.2 percent, a 4.8 percent throttling loss.

If 1,450 psia/965°F/630 psia "minimum steam conditions" are assumed, the theoretical steam rate ratio (estimate of additional flow required to get the same output assuming constant efficiency) results in an added flow passing capability requirement of about 7 percent (22.985/21.466 = 1.07).

If Figure 6 is read at 93.5 percent design flow (100.0/1.07 = 93.5), the bowl pressure is 93.8 percent, a 6.2 percent throttling loss. The difference in bowl pressure between with "minimum steam conditions" and without is 1.4 percent (6.2 - 4.8 = 1.4). A 1.0 percent loss from Figure 5 times a 1.4 percent loss from Figure 6 results in a 1.4 percent loss in available energy, just due to the requirement of "minimum steam." This 1.4 percent loss is equivalent to a 1.4 percent reduction in efficiency.

It is easy to realize after studying Figure 5 that the throttling loss is most important on turbines, or sections of turbines, with small pressure ratios such as short energy range noncondensing turbines or high pressure sections of extraction or admission turbines. Purchasers should keep this in mind when specifying the sizing criteria for this type of turbine.

One final word on turbine sizing. Oversizing can cause a reduction in turbine performance. Undersizing can lead to situations where the turbine capability is the limiting facet in the output of the process. Take some time during the specification process to study the specific sizing needs and record them on the supplementary data sheet.

SIZING OF STEAM PIPING

NEMA SM-23 gives recommendations for "maximum steam velocity, in piping," which are good guidelines. They are reproduced here as Table 7.

Table 7. Maximum Steam Velocity, in Piping.

	Noncondensing Turbine Ft./Sec.	*Condensing Turbine Ft./Sec.*
Inlet	175	175
Exhaust	250	450
Admission	175	175
Extraction	250	250

It is important for both the plant/process and the turbine designers to consider steam velocities and the associated pressure drops when sizing inlets, extractions, admissions, piping, valves, etc. All modes of continuous operation must be considered, not just normal design conditions. Maximum extraction or admission flow must be determined. It is important to point out, however, that higher than normal velocities and pressure drops may be acceptable for short time operating points such as startup or upset conditions.

Recommendation

Pressure drops in piping and valves external to the turbine must be considered by the plant/process designers.

Turbine designers will assume that the inlet or admission pressures specified are at the inlet flange of the trip throttle valve, and that exhaust and extraction pressures are at the turbine flanges unless specified otherwise by the purchaser. Pressure drops external to the turbine must be considered by the plant/process designers during turbine design specification. To reiterate, pressure drops to and from turbine sections with short energy ranges are most important.

TURBINE EFFICIENCY DEFINITIONS

It may seem trivial to propose definitions of efficiency. API 612 and NEMA SM-23 do not address efficiency. The truth of the matter is that, especially for multisection turbines, different turbine vendors may have different responses when asked to define turbine efficiency. The discrepancy is usually found in which losses are and which are not included in the efficiency calculation.

Recommendation

For comparisons, the efficiency definition of turbine shaft output divided by steam input is proposed.

The following simple definition is proposed for a straight through turbine.

$$\text{Turbine Efficiency} = \frac{\text{Turbine Shaft Output}}{\text{Steam Input}} = \frac{\text{SHP}}{\dfrac{\text{Flow (LB/HR)}}{\text{TSR (LB/HP-HR)}}}$$

Turbine shaft output is the power available to drive the driven equipment, and steam input is total throttle flow (FLOW) divided by the theoretical steam rate (TSR) of the steam from turbine inlet TTV flange to turbine exhaust flange.

For an extraction turbine, the following definition is proposed.

$$\text{Turbine Efficiency} = \frac{\text{Turbine Shaft Output}}{\text{Steam Input}} = \frac{\text{SHP}}{\dfrac{\text{FEXTR}}{\text{TSRHE}} + \dfrac{\text{(FTHROT-FEXTR)}}{\text{TSROA}}}$$

Turbine shaft output is the power available to drive the driven equipment and steam input is the sum of the total extraction flow (FEXTR) divided by the theoretical steam rate of the steam from turbine inlet TTV flange to the turbine extraction flange (TSRHE), plus the total throttle flow (FTHROT) minus the total extraction flow divided by the theoretical steam rate of the steam from turbine inlet TTV flange to the turbine exhaust flange (TSROA).

For an admission turbine, the following definition is proposed.

$$\text{Turbine Efficiency} = \frac{\text{Turbine Shaft Output}}{\text{Steam Input}} = \frac{\text{SHP}}{\dfrac{\text{FTHROT}}{\text{TSROA}} + \dfrac{\text{FADM}}{\text{TSREE}}}$$

Turbine shaft output is the power available to drive the driven equipment, and steam input is the sum of the total throttle flow (FTHROT) divided by the theoretical steam rate of the steam from turbine inlet TTV flange to the turbine exhaust flange (TSROA), plus the total admission flow (FADM) divided by the theoretical steam rate of the steam from turbine admission flange to the turbine exhaust flange (TSREE).

These definitions include all losses and, therefore, if used for each design under consideration, provide a true measure that can be used for comparison purposes.

TURBINE PERFORMANCE CALCULATIONS

Each vendor has a method of calculating aerodynamic and thermodynamic efficiency and performance of the turbine steam path. This method is usually calibrated based upon some kind of test data of similar type units. This internal efficiency is of the turbine stages only.

Recommendation

Propose that all losses be included in efficiency calculations for comparison purposes.

There are numerous additional losses which must be included in any efficiency or performance calculation of an entire turbine. If the efficiency definitions from above are used, these losses will, by definition, all be included. If, however, section efficiencies are quoted instead of overall turbine efficiencies, losses associated with the section efficiency calculation must also be indicated for a meaningful response.

For information, the following is a list of some of the additional losses that must be considered during turbine performance calculations.

- Turbine flow margins
- Control and TTV valve stem leakages
- Inlet throttling losses
  - TTV
  - valve chest
  - control valves
- Bearing losses (thrust and journal)
- Shaft end leakages
- Internal pressure drops to extraction flanges
- Exhaust leaving and throttling losses

When the output/input definition from above is used, all losses are included in the efficiency calculation.

EFFICIENCY GUARANTEES

API 612 states that "Turbines shall be capable of operation at normal power and speed with normal steam conditions. The steam rate (heat rate) certified by the manufacturer shall be at these conditions." NEMA SM-23 states that "Normal power and speed and steam conditions are those conditions found in usual operation and at which the steam rate will be guaranteed."

Neither reference mentions any tolerance on the quoted steam consumption and, therefore, it is assumed that any quotation of turbine performance is with no negative tolerance on efficiency.

Recommendation

Propose that turbine performance be quoted with no negative tolerance on efficiency. Consider "average" guarantee point in the right situation.

As a point of interest, API 617 for Compressors, on the other hand, requires capacity margin (flow passing capability) with no negative tolerance, but does allow for a four percent tolerance on power consumption. This tolerance on required power is one of the reasons that API 612 requires 10 percent power margin for steam turbine drivers.

Testing of steam turbines to prove quoted efficiencies can, and has been, the topic of separate papers. As far the purpose here is concerned, an important fact to consider when trying to make apples-to-apples comparisons of turbine offerings, is the possible difference in tolerance on quoted efficiency between vendors quoting to ASME PTC-6, and other vendors quoting to DIN. Basically, ASME PTC-6 allows no tolerance on performance, while DIN allows many tolerances, including provisions for aging, instrument tolerance, and manufacturing uncertainties.

Although it may seem obvious, during the specification of the turbine requirements at the proposal phase, be sure to specify all the parameters of the guarantee point. For a straight through turbine, there is usually no question other than confirmation that the "compressor normal point," for example, is, in fact, the guarantee point. For extraction or admission turbines: of throttle flow, extraction/admission flow, and power, two of these three parameters must be specified to fully define a guarantee point. Although flow passing capability has the biggest effect on turbine design, the turbine designer has some flexibility in skewing the design towards the flow requirements that will be used for evaluation.

One additional point to consider in the right situation: there may be cases when long-term operation at compressor points with very different powers and speeds is contemplated. The purchaser may want to specify an "artificial efficiency guarantee point" that is some kind of average among these long term operating points. The amount of time expected at each operating point would also be useful to the turbine vendors during the selection of the turbine design.

EFFICIENCY EVALUATION

Prior to going out for equipment bids, each purchaser has gone through an evaluation phase that has indicated, using some specific criteria, that the proposed project is worth pursuing. During this evaluation, cost of energy estimates were made, and a payback period of some amount of time was specified.

Since almost all special purpose mechanical drive turbines are custom designed, the designers have a lot of choices to make to come up with a suitable design. The purchaser wants the highest efficiency turbine for the lowest cost. Usually, these two parameters do not go together. The designer must determine the amount of hardware to include while still having a design whose price will be within the expectations of the purchaser.

Recommendation

Provide steam evaluation data to turbine vendors to allow "trade-off" evaluations.

A purchaser can help the turbine designers determine the amount of hardware to include by providing the evaluation criteria that have already been used to determine that the project is viable. If, for example, the addition of a stage to the turbine increases the efficiency by one percent, but also increases the cost by $ 50,000, should the additional stage be added or not? For some projects the answer is yes; for others, no. Turbine vendors could offer the options of a high cost, high efficiency design, and a low cost, low efficiency design. However, the correct option might be a design somewhere in between. If the value of steam at each pressure level and the length of the evaluation period is made available to the turbine vendors prior to quotation, a design that best fits the overall requirements is more likely to result.

OTHER EVALUATIONS

In addition to efficiency and cost of steam, there are often other facets of the overall turbine design which are important to the purchaser. In some cases, these design criteria can override all other constraints during the selection of the turbine.

For example, a short delivery essential to the needs of the project should be pointed out, including the evaluation that will be associated with actual deliveries that are shorter or longer than requested. Turbine size and/or weight are parameters that the design engineer can control if these are important to the specific situation.

There may be other criteria, features, or design parameters that are important to the purchaser. If so, these should be pointed out clearly to the turbine vendors during the proposal phase of the project.

ADDITIONAL WORK

This is just a start in trying to clarify all the design requirements of special purpose steam turbines during the proposal phase.

Among the topics that could also be addressed are:

- Double Automatic Extraction/Admission Turbines
- Uncontrolled Extraction/Admission Turbines
- Definition of Default Abnormal Steam Conditions
- Supplementary data sheets in metric units

Many of the concepts that have been presented here can also be applied to these types of turbines as well. For now, these additional topics will be saved for future discussions.

SUMMARY

Many of the important design details required by turbine vendors to propose a design that most closely matches the requirements of the project have been discussed. Continuous steam conditions, turbine powers and speeds, sizing requirements, efficiency considerations, and customer specific requirements all play a significant role in the design process.

The APPENDIX includes supplementary data sheets which can be used to summarize this additional data. It is not important that these data sheets be used. It is important, however, that the information found on the data sheets be provided to the turbine vendors. Specification of this information with the initial RFQ will reduce confusion and also improve turnaround time between RFQ and vendor quotation.

The default values proposed should be considered as benchmarks from which to start. If the default values are not appropriate for a particular application, this should be so stated. The supplementary data sheets provide an opportunity to override default values for each design parameter.

Recommendation

Whether default or actual data are used, it is proposed that continuous steam conditions for mechanical design, turbine sizing criteria, value of vendor flow margin, continuous powers, and continuous speeds that have been used during the proposal design be included in the proposal document provided to the purchaser.

APPENDIX

Figure A-1. Straight Through Turbine Supplementary Data Sheet.

Job No.__________ Item No.__________

Purch. Order No.__________ Date __________

Requisition No.__________

Inquiry No.__________

By __________

Revision__________ Date __________

Supplementary Special-Purpose
Steam Turbine Data Sheet
Customary Units

Straight Through Turbine

Continuous Steam Conditions for Mechanical Design

	Inlet Pressure	Inlet Temperature	Condensing Exhaust Pressure	Noncondensing Exhaust Pressure
Maximum	(1.05 × Normal) psig	(Normal + 15 F) deg °F	(Normal + 1.0") "HgA	(Normal × 1.1 or + 10 psi) psig
Normal	(cs) psig	(cs) deg °F	(cs) "HgA	(cs) psig
Minimum	(Normal) psig	(Normal) deg °F	(0.5 ") "HgA	(Normal × 0.8 or – 10 psi) psig

"cs" indicates "Customer Specified"

Turbine Efficiency Guarantee Point Definition

Flow * __________ lb/hb (cs)
Power * __________ hp (c. normal)
Speed __________ rpm (normal)
Inlet Pressure __________ psig (normal)
Inlet Temperature __________ deg °F (normal)
Exhaust Pressure __________ " HgA (normal) psig

*Specify Flow or Power but not both

Turbine Flow Passing Capability Design Point

Flow * __________ lb/hr (cs)
Power * __________ hp (t. rated)
Speed __________ rpm (100% & 105%)
Inlet Pressure __________ psig (min)
Inlet Temperature __________ deg °F (min)
Exhaust Pressure __________ " HgA psig (max)
Flow Passing Margin = __________ (5%)

Continuous Powers for Mechanical Design ______ (hp) ______		Continuous Speeds for Mechanical Design ______ (rpm) ______		Value of Steam:	
Turbine Rated	______ (C. Rated × 1.1)	Maximum Continuous	______ (105 %)	______	$ / lb/hp Throttle Steam
Compressor Rated	______ (cs)	100%	______ (cs)	______	$ / lb/hr Exhaust Steam (non-cond)
Compressor Normal	______ (cs)	Normal	______ (cs)	______	Years Evaluation Period
Minimum	______ (C. Norm × 0.8)	Minimum	______ (80 %)	Site Elevation ______ ft	(Sea Level)

Other Evaluation Criteria:

____

____

____

____

____

Data in parentheses indicate default values

Figure A-2. Single Automatic Extraction Turbine Supplementary Data Sheet.

Job No. ______________________ Item No. ______________________
Purch. Order No. ______________________ Date ______________________
Requisition No. ____
Inquiry No. ____
By ____
Revision ______________________ Date ______________________

Supplementary Special-Purpose
Steam Turbine Data Sheet
Customary Units

Single Automatic Extraction Turbine

Continuous Steam Conditions for Mechanical Design

	Inlet Pressure	Inlet Temperature	Extraction Pressure	Condensing Exhaust Pressure	Noncondensing Exhaust Pressure
Maximum	(1.05 × Normal) psig	(Normal + 15 F deg °F	(Normal × 1.1 or + 10 psi psig	(Normal + 1.0") "HgA	(Normal × 1.1 or + 10 psi psig
Normal	(cs) psig	(cs)	(cs) psig	(cs) "HgA	(cs) psig
Minimum	(Normal) psig	(Normal) deg °F	(Normal × 0.8 or – 10 psi) psig	(0.5 ") "HgA	(Normal × 0.8 or – 10 psi) psig

"cs" indicates Customer Specified"

Turbine Efficiency Guarantee Point Definition

Throttle Flow * ______ lb/hr (cs)
Extraction Flow* ______ lb/hr (cs)
Power * ______ hp (C. Normal)
Speed ______ rpm (Normal)
Inlet Pressure ______ psig (Normal)
Inlet Temperature ______ deg °F (Normal)
Extraction Pressure ______ psig (Normal)
Exhaust Pressure ______ " HgA psig (Normal)

*Specify only two of three

Turbine Flow Passing Capability High Pressure Section Design Point

Throttle Flow * ______ lb/hr
Speed ______ rpm (100 % & 105 %)
Inlet Pressure ______ psig (Min)
Inlet Temperature ______ deg °F (Max)
Extraction Pressure ______ psig (Max)
Flow Passing Margin = ______ (5 %)

Turbine Flow Passing Capability Low Pressure Section Design Point

LP Section Flow ______ lb/hr
Speed ______ rpm (100 % & 105 %)
Extraction Pressure ______ psig (Min)
Extraction Temperature ______ deg °F (Max)
Exhaust Pressure ______ " HgA (Max)
Flow Passing Margin = ______ (5 %)

Specific extraction flow requirement while developing turbinerated power? ______ Yes / No (No) lb/hr = ______
Specified maximum LP section flow? ______ Yes / No (No) lb/hr= ______
Specified point with zero extraction? ______ hp = ______ rpm = ______
Hold extraction pressure at zero extraction point? ______ Y/N (Y)
Maximum Extraction Flow = ______ lb/hr

Continuous Powers for Mechanical Design ______ (hp) ______		Continuous Speeds for Mechanical Design ______ (rpm) ______		Value of Steam:	
Turbine Rated	______ (C. Rated × 1.1)	Maximum Continuous	______ (105 %)	______	$ / lb/hp Throttle Steam
Compressor Rated	______ (cs)	100%	______ (cs)	______	$ / lb/hr Extraction Steam
				______	$ / lb/hr Exhaust Steam (non-cond)
Compressor Normal	______ (cs)	Normal	______ (cs)	______	Years Evaluation Period
Minimum	______ (C. Norm × 0.8)	Minimum	______ (80 %)	Site Elevation ______ ft	(Sea Level)

Other Evaluation Criteria:

____

____

____

____

____

Data in parentheses indicate default values

Figure A-3. Single Automatic Admission Turbine Supplementary Data Sheet.

Job No. ______________________ Item No. ______________________
Purch. Order No. ______________________ Date ______________________
Requisition No. ____
Inquiry No. ____
By ____
Revision ______________________ Date ______________________

Supplementary Special-Purpose
Steam Turbine Data Sheet
Customary Units

Single Automatic Admission Turbine

Continuous Steam Conditions for Mechanical Design

	Inlet Pressure	Inlet Temperature	Admission Pressure	Admission Temperature	Condensing Exhaust Pressure	Noncondensing Exhaust Pressure
Maximum	(1.05 × Normal) psig	(Normal + 15 F) deg °F	(Normal × 1.1 or + 10 psi) psig	(Normal + 15F deg °F	(Normal + 1.0") "HgA	(Normal × 1.1 or + 10 psi) psig
Normal	(cs) psig	(cs) deg °F	(cs) psig	(cs) deg °F	(cs) "HgA	(cs) psig
Minimum	(Normal) psig	(Normal) deg °F	(Normal × 0.8 or –10 psi) psig	(Normal) deg°F	(0.5") "HgA	(Normal × 0.8 or – 10 psi) psig

"cs" indicates "Customer Specified"

Turbine Efficiency Guarantee Point Definition

Throttle Flow *	______	lb/hr	(cs)
Admission Flow*	______	lb/hr	(cs)
Power *	______	hp	(C. Normal)
Speed	______	rpm	(Normal)
Inlet Pressure	______	psig	(Normal)
Inlet Temperature	______	deg °F	(Normal)
Admission Pressure	______	psig	(Normal)
Admission Temperature	______	deg °F	(Normal)
Exhaust Pressure	______	" HgA psig	(Normal)

*Specify only two of three

Turbine Flow Passing Capability High Pressure Section Design Point

Throttle Flow	______	lb/hr	
Speed	______	rpm	(100 % & 105 %)
Inlet Pressure	______	psig	(Min)
Inlet Temperature	______	deg °F	(Max)
Admission Pressure	______	psig	(Max)

Flow Passing Margin = ________ (5 %)

Turbine Flow Passing Capability Low Pressure Section Design Point

LP Section Flow	______	lb/hr	
Speed	______	rpm	(100 % & 105 %)
Admission Pressure	______	psig	(Min)
Admission Temperature	______	deg °F	(Max)
Exhaust Pressure	______	" HgA	(Max)

Flow Passing Margin = ________ (5 %)

Specific admission flow requirement while developing turbine rated power? ______ Yes / No (No) lb/hr = ____________

Specified maximum LP sectionflow? ______ Yes / No (No) lb/hr = ____________

Specified point with zero admission? ________ hp = ________ rpm = ________

Hold admission pressure at zero admission point? ______ Y/N (Y)

Maximum Admission Flow = __________ lb/hr

Continuous Powers for Mechanical Design (hp)			Continuous Speeds for Mechanical Design (rpm)			Value of Steam:	
Turbine Rated	______	(C. Rated × 1.1)	Maximum Continuous	______	(105 %)	______	$ / lb/hp Throttle Steam
Compressor Rated	______	(cs)	100%	______	(cs)	______	$ / lb/hr Admission Steam
						______	$ / lb/hr Exhaust Steam (non-cond)
Compressor Normal	______		Norrnal	______	(cs)	______	Years Evaluation Period
Minimum	______	(C. Norm × 0.8)	Minimum	______	(80 %)	Site Elevation ______ ft	(Sea Level)

Other Evaluation Criteria:

____

____

____

____

____

Data in parentheses indicate default values

BIBLIOGRAPHY

"Special Purpose Steam Turbines For Refinery Services," API Standard 612, Third Edition (November 1987).

"Centrifugal Compressors for General Refinery Service," API Standard 617 Fifth Edition (April 1988).

"Steam Turbines for Mechanical Drive Service," NEMA Standard SM-23 (1985).