USER INSIGHTS FOR THE EFFECTIVE PURCHASE OF NEW TURBOMACHINERY

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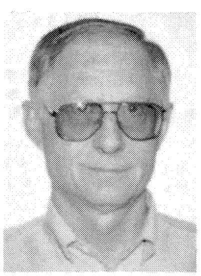

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ABSTRACT

As organizations reengineer to become more competitive and as people are exposed to the purchase of new machinery in an increasingly competitive international market, an acquaintance with the activities needed for effective purchase of new turbomachinery becomes more essential. Insights will be provided into the essential activities in the effective purchase of new turbomachinery. A basic description of the 1) specification, 2) quotation evaluation, 3) purchase, 4) post order coordination and 5) shop testing activities involved is included. The need for each of the five activities is also addressed and some of the user-related opportunities/problems are identified. Some of the variations of these activities such as user purchase, sole sourcing, duplication of existing machines, etc., are also addressed. The user can, through a better understanding, become more effectively involved in the procurement process and achieve a higher quality/lower cost installation.

Many project schedules require that turbomachinery be purchased as soon as possible. This means that the machinery could be purchased while most of the design engineering groups are being mobilized for project execution. The user's economic impetus to complete projects within a predefined schedule frequently mandates that project personnel make many decisions at the onset of a project to effect the early purchase of the machinery. Some adjustments/changes to these early decisions are inevitable as the project evolves, but early participation by user representatives can frequently minimize changes. In most cases, the user's participation in the purchase of turbomachinery is beneficial. On the other hand, users unfamiliar with the activities involved in the purchase of machinery could find that their input in the later stages of a project is met with resistance or cannot be accommodated by the project, as a result of the negative impact it would have on the overall project objectives.

These insights will also provide manufacturers with a better understanding of purchase activities and will enable manufacturers to apply the necessary resources needed to effectively support the project. Avoiding the antagonistic relationships that can develop between the manufacturer, contractor and user will permit the resources of each organization to be better focused on resolving the technical issues that inevitably develop on a project.

INTRODUCTION

Turbomachinery is unique because the designs are precise, dynamic, and proprietary. Lead times for delivery of new turbomachinery are generally the critical item in many project schedules. A generic schedule of some of the activities related to the purchase of new turbomachinery is shown in Figure 1. The design effort and the resulting construction effort for the facility in which the machine will be installed are highly dependent on receipt of the manufacturer's documentation. This documentation is unique to each proprietary design. Failures of the precise, high speed designs of current turbomachinery can have catastrophic effects on petroleum and chemical facilities. However, many industrial projects involve the purchase and installation of new or modified turbomachinery by an organization not involved in the day-to-day operation of the plant. This organization could be the company's central engineering staff, a contracted engineering organization, or both. Whichever the case, the effective purchase of turbomachinery will require the participation of the operating plant personnel. The representatives of the operating plant, user, should be familiar with the operation and repair of existing plant turbomachinery.

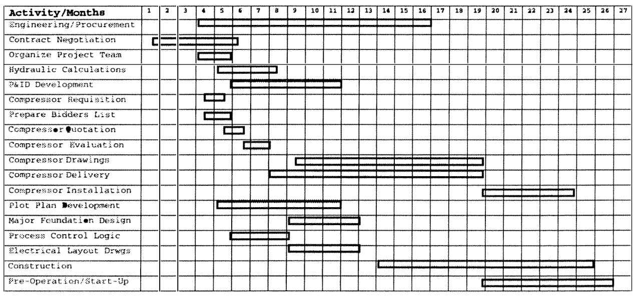

Figure 1. Generic Schedule of Turbomachinery Purchase Activities.

Most refinery, petrochemical, and chemical plant projects are conceived to improve profitability. Exceptions would involve environmental, safety and similar projects. Most projects are based on an expected return on investment. Projects not conceived to improve profitability generally are expected to minimize costs. However, all of these projects are based on a scope including materials, engineering, and construction costs. The scope of either type of project could be as simple as modifying a machine, or it could be as complex as a complete grassroots facility. But, in both cases, the plant owner expects to minimize costs and maximize the return on investment through the sale of the plant product. It should be noted that for plants with an extended design life, the user's experience could show that the maintenances costs do not justify minimizing investment costs.

PROJECT SCOPE DEFINITION

Developing the scope definition for a project is the first step and an important step in a successful project. Since the decision to proceed on most projects is based on an initial cost estimate for project execution, the scope for the feasibility estimate will serve as the basis for the budget to which detailed engineering will be done and materials will be procured. Some processes are offered as standardized packages and the engineering of the entire facility follows a preestablished scope; for example, air separation plants and ammonia plants. Another method of establishing the scope of a project is to duplicate an existing design. On larger, more complex projects, a separate engineering organization could assist in the development of the project scope. The team developing the feasibility scope is generally a much smaller group than required to execute detailed engineering. This scope is developed as the process scheme is selected and/or being developed. The process group could make a preliminary selection of the machine type for various services or, for less familiar services, a machinery specialist could be requested to study various arrangements and make a recommendation. Since commercial feasibility needs to be established first, input from the operating plant's machinery representatives is typically not solicited. On most projects, there are usually additional process reviews and refinements in the early stages of a project that permit reflection on and adjustment to the types of machines selected during the project scope definition.

After a project's feasibility has been established and detail design is authorized, an engineering organization is selected. Companies/plants having engineering organizations may execute smaller projects. For companies/plants without an in-house engineering organization and for larger projects, a contract can be arranged with a separate engineering organization. The contractual arrangements for execution of the project by a separate engineering organization vary and could be based on a fixed cost, a cost reimbursable basis, a not to exceed basis or another arrangement. Generally engineering organizations adapt their procedures to the type of contract, but the user could find that contractual restraints imposed on the contractor impose restraints on the latitude available to the project team to incorporate modifications to the initial scope. Any inconsistencies between the user's needs and the contract with the engineering organization should be brought to the project team's attention as early as possible for resolution and for minimum consequences.

For large complex projects, the owner's organization could organize a project management team or contract project management to another organization to interface with the contracted engineering organization. The owner's project management team is usually located in the contracted engineering organization's facilities. The management team could consist of administrative personnel and, in some cases, includes select engineering representatives. Companies having in-house engineering organizations usually draw from that organization to manage large projects. Due to the dynamic nature of turbomachinery, the variety of available proprietary designs and the expected reliability, the user's input to the project team is needed. His acquaintance with the site specific requirements and his experience with machines that have performed effectively within his organization are essential to the purchase of a machine that will perform effectively in a new installation.

Often, the engineering and procurement are provided by one organization and construction by another organization. For large projects involving several processes, it is not unusual to have more than one contracted engineering organization executing a project. In most cases, the projects have unique contractual arrangements and unique schedules making coordination of machinery purchases among projects difficult. The need and extent of coordination among various engineering organizations for machinery purchases and the impact the coordination could have on each project should be accessed as early as possible (Figure 1).

The owner's authorization to proceed with design on some large complex projects is conditional. The conditions vary and may involve project scope refinement/confirmation, product market conditions confirmation, pending governmental regulation passage, etc.

ORGANIZATION OF THE PROJECT TEAM

One of the initial steps in execution of a project by an engineering organization is organizing a team. A typical project organization chart is provided in Figure 2. On large projects, this team may eventually involve hundreds of people. As the team is being organized, schedules and work execution plans are developed for the process, project engineering, mechanical, piping, instrumentation, civil, electrical engineering activities, along with the purchasing, inspection and construction activities. These work execution plans are based on established procedures of the organization selected to execute the project and the scope on which the feasibility of the project was based. The profitability of a project frequently involves minimizing investment costs along with meeting a forthcoming change in raw plant feedstock, a critical market demand for the plant product, a planned plant turnaround schedule, enactment of environmental regulations, or any number of other needs. This almost always defines a date by which the owner expects the plant to begin successful operation. To this end, the project team begins to evaluate the need for engineering information to support detailed design of the facility and for procurement of large, long lead time materials for the project to meet construction schedules. Turbomachinery is almost always on the critical path of a project, since its design is proprietary, because the specification, selection and manufacturing cycle is generally one of the longest on the project and because installation can be more complex than other equipment on the project. While the project team's focus early in the project is on budgets and schedules, reliability of the turbomachinery usually remains an important owner/user concern.

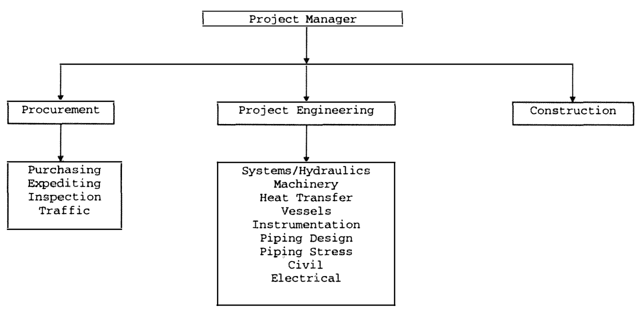

Figure 2. Typical Project Organization Chart.

The machinery engineer for the compressor, electric generator, fan, or other machines will almost certainly be among the first assigned to the project. The machinery engineer will, for large complex machinery, prepare the data sheets, the specifications, and the requisition, evaluate the manufacturer's quotations, organize and attend pre-award and coordination meetings, review manufacturer documentation, and witness complex shop testing. The machinery engineer should coordinate the technical requirements of other engineering disciplines, the user's requirements and any manufacturer technical correspondence concerning the machinery being purchased. After the engineering organization's machinery engineer is assigned to the project and has developed an understanding of the machinery needed for the project, a meeting should be arranged with the user. The timing of this meeting is critical. The machinery engineer and the user should both become familiar with the project scope in advance of the meeting, but the project execution should not have progressed to the extent that execution plans have been finalized.

As a minimum, the following points should be addressed at the machinery kickoff meeting.

The Scope of the Project

Among the issues to be addressed are the type of machines involved, the specifications and data sheets to be used for specification, and any compromises and/or assumptions made to enhance the feasibility of the project. As the project scope is developed and costs evaluated, it is not unusual for compromises to be made. These compromises may not be apparent in the project documents nor known by the user. The user should undertake resolution of any differences in expected scope with his project management team. Examples of compromises are:

- The owner's corporate specifications may have been deleted from the scope to minimize the project cost.

- The number of machines selected may have been based on minimizing the project cost without consideration for operating costs and/or flexibility.

- The types of machines selected for budgeting purposes may have been based solely on minimizing initial cost without regard for the user's previous experience with operating limitations with the same types of machinery.

- Packaging of machines may have been maximized to minimize installation costs without regard to reliability and/or maintenance considerations.

On some projects the turbomachinery may be sole sourced, duplicated from another project or purchased by the user. Although cost of turbomachinery is usually comparatively high on projects, the schedule for project completion or other circumstances may dictate that the bid/evaluate cycle be omitted. Data sheets and specifications are generally required to convey the scope of supply to the manufacturer and the manufacturer still needs to advise the purchaser of the extent of compliance. But in many cases, both of these activities can be accomplished in an extended meeting prior to finalization of the commercial order. When a machine is sole sourced to meet project schedules, the user should participate in reviewing the manufacturer's scope of supply prior to order placement. The user's involvement in establishing the scope of supply at the time of order placement should minimize post order changes that could be resisted by the project team because of potential delays in project completion.

Some projects require duplication of existing machines. This may be an expansion to an existing processing unit in the user's facility or duplication of an entire facility located elsewhere. The term duplication needs to be clearly understood, since it is used to describe a machine that is interchangeable in all respects and a machine of like kind. An order for a duplicate machine that is interchangeable in all respects with an existing machine should be purchased by reference to the existing machine manufacturer's serial number, shop order number, etc. Data sheets and specifications are generally not necessary and can lead to confusion if any information contained therein is different than the construction of the existing machine. A machine of like kind generally refers to a machine that is similar in some respects, but that is not necessarily interchangeable. The purchase of a machine of like kind may vary to one with interchangeable parts but different in other respects to one of the same model. Purchase of machines of like kind generally require specifications and data sheets to define the manufacturer's scope of supply. However, the user should provide the project explicit guidance in both cases concerning the extent of machine duplication required.

The Available Engineering Resources/Skills

Engineering organizations are usually involved in many types of projects with engineering schedule durations of at least a year. It is usually not practical to maintain an engineering staff for full time assignment to projects with expertise in the variety of compression machinery listed below and with the expertise in the variety of designs available from international suppliers.

- Centrifugal fans
- Axial fans
- Straight lobe blowers
- Curved lobe blowers
- Centrifugal compressors
- Axial compressors
- High speed reciprocating compressors
- Low speed reciprocating compressors
- Integral reciprocating compressors
- Oil flooded screw compressors

- Dry screw compressors
- Steam turbines
- Aeroderivative gas turbines
- Heavy duty gas turbines
- Induction motors
- Synchronous motors
- Hot gas expanders
- Cryogenic expanders
- Diesel engines
- Gas engines
- Helical gears

Due to the proprietary nature of turbomachinery designs, engineering organizations rely on the manufacturer's expertise. In some cases, the machinery engineer for a project may not have experience in purchasing a particular type of machine necessary for the project, but the expertise with an application of that type of machine can usually be found within the engineering organization's staff. As a minimum, the engineering organization's machinery engineer(s) should have an understanding of turbomachinery concepts so that he can recognize areas that require clarification/explanation, and so that he can effectively apply his understanding and any available resources to evaluate these clarifications/explanations. He should also have sufficient knowledge of the other engineering design discipline activities to effectively coordinate their needs. The user should review the turbomachinery applications on the project and the resources available to the engineering organization and should develop plans to supplement any perceived staff deficiencies of the engineering organization.

Project Team Activities

The project organization and lines of communication. It is generally recognized that a free exchange of information between the user and engineering organization is essential for successful project execution. However, the impact of scope changes and/or execution plan modifications to the project schedule and/or budget must be assessed by the management team(s). The user's anticipation of the project team's requirements for approval of scope changes can in most cases facilitate resolution and project completion.

Activities to procure the equipment and support the design of the facility. A typical flow chart of the typical steps to procure turbomachinery is shown in Figure 3. Although project execution varies with each organization and individual project execution plans vary to suit the owner's expectations, the activities shown in Figure 3 are considered essential.

The requisition format. The user should verify that the format is clear and concise without significant redundancies. It should contain (as a minimum) a list of major equipment included, a list of applicable specifications, and a concise listing of documents necessary for engineering/design of the facility and for installation, operation, and maintenance of the machine. The user's familiarity with the engineering organization's requisition format will also facilitate future reviews and references.

The project schedule and any associated restraints on procurement of the machinery. A short project schedule could require that the machinery specifications for quotation be issued incomplete and/or be issued to a minimum of manufacturers, that the evaluation of the machinery quotations be abbreviated, or that adjustments be made to the user's expected participation.

Engineering organization quality assurance review/approvals and agreed upon user reviews/approvals. The user

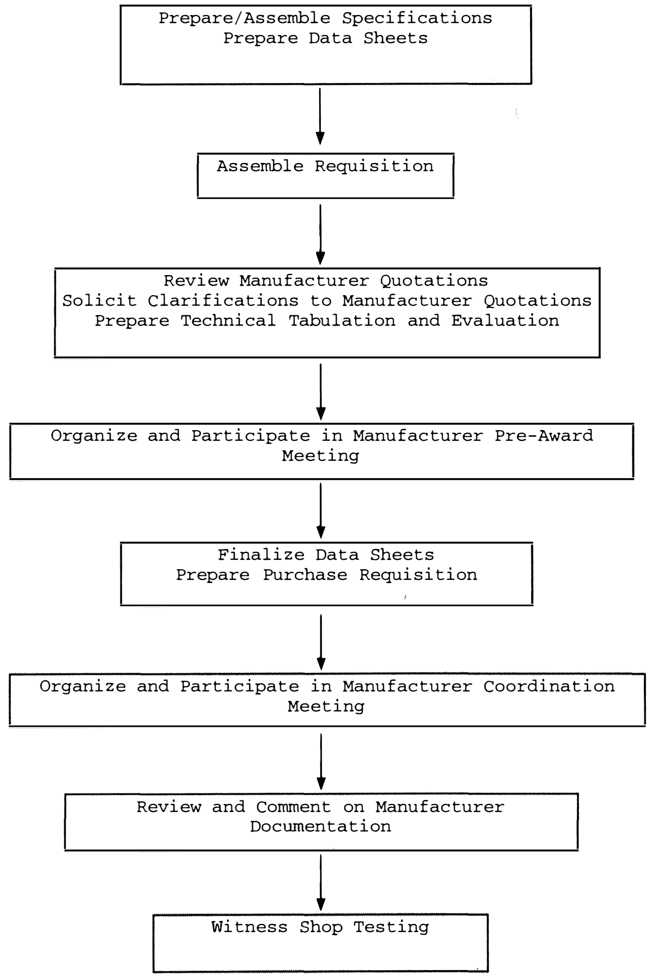

Figure 3. Typical Steps in the Purchase of New Turbomachinery.

may be involved in the review/approval of machinery data sheets, machinery specifications, ancillaries specifications, machinery requisitions, and manufacturer documentation. He may also attend project piping and instrument diagram reviews, project model reviews, machinery manufacturer meetings and selected shop inspection/testing activities. The level of expected user participation should be addressed early in the project so that expectations can be anticipated as detailed design of the facility gets underway. The user can also elect to waive reviews if the engineering organization's review procedures meet the user's needs.

Manufacturers that are acceptable for supply of the machinery and ancillaries. These names are considered confidential and access is usually restricted, but this information is necessary for the requisitioning engineer. This list will guide the requisitioning engineer to sources of preliminary information necessary for development of early plot plans, electrical one lines, etc. without consuming the resources of manufacturers who will not be given an opportunity to bid later. The user should also identify manufacturers whose machinery has not performed as expected, or whose aftermarket support is unusually favorable or unfavorable.

The user should also address the preferred manufacturers for ancillary system components. The development of a list of preferred manufacturers for instrumentation, electrical and piping components is frequently not prioritized early in the project, since design for procurement of these items can take place much later in the project, but it will be needed before an order is placed for a machine.

The project distribution of information (including manufacturer documentation). Frequently, the user becomes alienated from the project as it is executed because of other obligations and is not informed of significant project decisions/events. Having addressed the aforementioned topics, the user should make certain that both the owner's project team and the engineering organization will supply the information needed to maintain active involvement in the project. But, the user should be selective in requesting distribution of project documentation as the multiple issues of various discipline documents can become overwhelming.

Refined Estimate

Early in the project, the engineering disciplines are usually required to develop a second estimate of man-hour expenditures for the remainder of the project, a staffing plan and in some cases material cost estimates. Although these are administrative activities, they are the benchmark to which the project's engineering team will execute the design phase of the project. This second scope definition/estimate is developed early in the project and may serve as a refinement to the initial scope definition. It could encompass refinements that may have evolved in the development of the process that occurred after the initial estimate, a more accurate pricing basis and the engineering organization's plan for execution of the project. After the owner's and engineering organization's project management teams agree on a final budget and schedule for a project, changes in the project scope generally require justification and a written approval by both project management teams. Since even simple changes can have serious consequences to the project as the machine procurement progresses and the design of the facility is developed, it is incumbent on the user to address all the requirements as early as possible Refer to Figure 4 for a comparison between expected and typical user involvement in the purchase of turbomachinery.

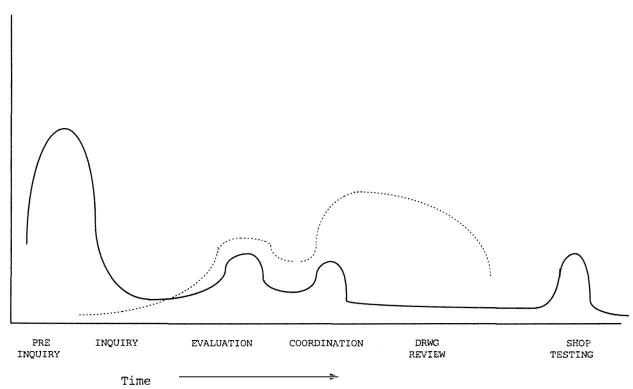

Figure 4. Expected versus Typical User Involvement in Turbomachinery Purchase.

SPECIFICATION

The requisitioning engineer begins assimilating the information for the requisition(s) almost immediately after joining the project team. This information includes the following:

• *Preliminary process flows, pressures, gas compositions, driver type, etc. to develop a concept of the machine best suited to the application.* This will give the machinery engineer an opportunity to access the features of different designs available and if necessary request additional information necessary to select a machine type.

• *Machinery specifications.* The user should understand the source of any specifications used on the project. Many large organizations maintain specifications, but even these specifications can be superseded by later editions of API Standards, are generally limited to the more frequently purchased turbomachinery, and are considered too stringent for some applications. The user should be aware that without user specifications, the engineering organization may use specifications from previous projects which may contain requirements that are not applicable or may not meet the users needs (e.g., refinery specifications used for a cogeneration facility or oil field production specifications used for a refinery).

• *Instrumentation and electrical specifications for the ancillary equipment.* The activities in both of these engineering disciplines usually peak in the last quarter of a project, however, on many projects expectations are that the machinery be provided with instruments and electrical devices in accordance with the requirements for the remainder of the project. Unless the instrument and electrical requirements are finalized early in the project or the scope of instrumentation furnished with the machinery is minimized, the instrumentation and electrical requirements developed later in the project can have a significant impact on machinery purchase. The user's early involvement in identifying the requirements for instrumentation and electrical ancillaries and minimizing changes that do not enhance the project can avoid an inordinate amount of time in reconciling discrepancies between manufacturer's scope and project requirements.

• *Process hydraulic calculations/flow diagrams.* These documents serve as the basis for the operating conditions and control philosophy. The machinery engineer should understand the process variations that may influence the operation of the machinery. Compressors may need to start with full suction and/or settle-out pressure or may need to operate on gases with variable molecular weights or pressures. Generators may need to be started without external utilities. The user should independently verify that all operating conditions have been addressed, including those that may not be a design case, but that are known to exist at other similar facilities (i.e., failure of upstream process equipment to perform as expected as a result of process upsets, operation at off-design conditions, machine fouling, etc.)

• *Miscellaneous.* Electrical area classifications, equipment tag numbers, and project procedures.

• *Site data.* This information on plant utilities, site conditions, codes, local regulations, etc., is usually assimilated into one document and distributed for the team's use. The user should review this information to identify omissions and errors. For example, project team members do not always recognize that machinery ratings based on the minimum/maximum ambient and/or coolant conditions can result in nonoptimized ratings. Coolants that contain silt, debris or other contaminants may render typical oil cooler designs troublesome after installation, but may go unnoticed by other project team members. Steam contaminants, cooling water temperature variations, gas turbine fuel contaminants, environmental regulations (noise and emissions), environmental contaminants (dust, chemicals, salt spray, etc.) along with many other site related issues are not always recognized by the project team and could have a negative impact on the machine's reliability if not addressed.

This information along with additional information to define the manufacturer's scope is generally consolidated on data sheets or in some cases project specific specifications. Data sheets are a convenient and effective method of handling information subject to change as the order progresses. The data sheet format also permits usage of standardized and preprinted specifications for a variety of machines and projects. Although the recent advent of electronic media permit tailoring specifications to each service, standardized specifications can be used repetitively without extensive reviews by each project team and each manufacturer for different projects and various applications. Data sheets for turbomachinery are frequently based on the data sheets found in the appendix of the API standards. However, it should be noted that these data sheets should be used judiciously. The API documents may need to be supplemented/modified (gas seals, gas turb., air filters for process compressors, control panels, etc.) to adequately define the requirements for a particular application. Axial compressors, single stage overhung compressors/blowers, integral gear compressors used in process services, cryogenic and hot gas expanders, oil flooded screw compressors, and electric generators do not have standardized data sheets in widespread use. The user should recognize that the primary purpose of the data sheets with the relevant specifications and any diagrams is to convey the requirements to the machinery manufacturers and to define a minimum scope. Caution should be used in including data sheets for minor peripherals / instrumentation in the requisition. While it may seem appropriate to include data sheets for small motors, oil pumps, oil coolers, etc., the benefit of incorporating these data sheets in a purchase order should be considered *vs* the added value. Firm information for the minor peripherals is not often available until several weeks after the machine has been purchased. This, together with a perception by project team members that missing information on any data sheet at the time of purchase implies incomplete scope definition, may create unnecessary delays and additional costs to the project to get unnecessary data sheet information for the peripherals.

Specifications should be concise and reflect the minimum requirements. To facilitate use and avoid confusing duplication and contradictions, most turbomachinery specifications are prepared as modifications to the appropriate API Standard. Each user machinery specification should contain a listing of related specifications and a reference in the text of the user specification that identifies the applicability (e.g., "Local control panels shall be furnished in accordance with User Specification ABC-1234, Local Outdoor Instrument and Control Panels"). One variation of this reference is the specification tree that can result (See APPENDIX). References in each specification can create a tree with branches that can reference to orifice plates, wiring, etc. The writers of the specifications may not be aware of this branching or may not have a clear concept of how the specifications are to be applied. But, any understanding of specification application is usually lost when the specifications are distributed among the various disciplines on a project. The referenced specification's applicability should also be obvious. Examples of common specifications whose applicability is questioned are:

- Piping for process units
- Painting
- Insulation
- Plant instrumentation

Each of the above specification types are usually general and address the requirements of the entire facility. These types of specifications also address details that are rarely applied to a specific machine, but that could apply by strict interpretation. The user should be familiar with the correct application of the specifications and should be prepared to assist in avoiding the inclusion of unnecessary specifications. Without references to other specifications, applicable user specifications can be easily over or under utilized. The addition of unnecessary specifications can have significant cost impacts, whereas the omission of appropriate specifications usually results in requirements not being met. With schedule and budget constraints, the variety of machinery and the variety of industry standards available, the user's assistance in recognizing when specifications need clarification and assistance in identifying the areas needing amendment can also have a significant impact on the quality of the machine installation.

As the information for the machine is being assimilated, the requisition for quotation is started. As a minimum, it should contain a list of machinery items included, a listing of applicable specifications (with a revision and/or date), a concise list of proposal requirements, and a listing of post award manufacturer documentation requirements with expected submittal times. These requirements should be realistic and clear. An example of proposal requirements are as follows:

- Data sheets for each major component with manufacturer supplied information added to the data sheets and any variance to the specified requirements clearly annotated. (This information will provide a concise and uniform source of basic information about the machine offered and will facilitate completion of the technical evaluation of the quotations.)

- Predicted performance curves for each major component including centrifugal compressor section curves, steam turbine steam flow *vs* horsepower and speed, gas turbine output corrected to site conditions. (This information will provide a description of machine's performance capabilities. However, it should be noted that to make the comparison of machine performance easier, the curves should be drawn to a common scale.)

- A manufacturer statement confirming that the proposal is in complete compliance with the specifications, diagrams, and drawings and all referenced attachments to these documents except as noted. Each comment/exception should clearly state what will be provided in lieu of the stated requirement and the impact on the quotation for full compliance. If it is not possible or practical to comply with the stated requirements, the manufacturer should explain why. The manufacturer should be advised that only those exceptions stated in the above list will be recognized in the evaluation of the quotation and any subsequent order. (This information will provide a concise source for determining the extent of compliance with the specifications. It should be noted that the conciseness of the manufacturer's exceptions will usually parallel the conciseness of the specifications. Also, if the specifications are standardized and not tailored to each application, the turbomachinery manufacturer can utilize exceptions and interpretations from previous orders.)

- Installation lists for the major components. (This information is needed to establish the manufacturer's level of experience with the proposed design.)

- Typical cross sectional drawings for the major components (This information is used to understand the design features of the proposed machine.)

- Preliminary composite outline drawing of the major components showing the overall dimensions, dimensioned major piping dimensions, weights, etc. (This information is used to support the initial piping and civil design efforts.)

The manufacturer documentation requirements can go unappreciated by many user representatives. However, these documents are necessary to complete the project design. Late and incomplete documentation can lead to aggressive expediting of the manufacturer, which usually precipitates uncooperative attitudes, to delays in the design effort that can precipitate excessive man-hour expenditures and to disgruntled owner representatives because of the unpleasant situation created on the project.

Although an absolutely complete, accurate, and concise requisition package is the optimum situation, the project schedule frequently requires that quotations be solicited with documents that are not the optimum. As the information to support the machinery requisition develops it becomes obvious that risks associated with delaying the requisition and delaying the completion of the project are not justifiable. Users recognizing the constraints can minimize any deficiencies by supporting the procurement process with any inputs needed and accepting deficiencies that can be addressed later.

A fundamental prerequisite for most technical evaluations is that each manufacturer invited to submit a quotation is a qualified manufacturer. In situations requiring the extension of the established turbomachinery technology and/or large complex orders, meetings may be necessary with the known manufacturers to establish a list of qualified manufacturers.

QUOTATION TECHNICAL EVALUATION

After issuance of the requisition, the machinery engineer is generally expected to continue working on the preparation of requisitions for other machinery, to provide information to support other engineering discipline activities and to start to prepare for the technical evaluation of the turbomachinery quotations. Dialog with manufacturers quoting on machinery is usually minimized and restricted to the purchasing group of the engineering organization to maintain a fair and equitable bidding process. The user should respect these dialogue restrictions, because well intended user guidance passed along directly to the manufacturer can work to the user's and manufacturer's disadvantage. In some cases, the manufacturer's expect direct dialogue with the user and other owner representatives and can easily overlook significant guidance from the project team. While the manufacturers are preparing the quotations, the project team is probably conducting the initial reviews of the project piping and instrument diagrams. The user and other owner representatives should be involved in these reviews. Although the review of the P&IDs can last for several days, involvement can lead to a better understanding of the how the machine will be integrated into the remainder of the facility. As information becomes available from the project team, the machinery engineer will in most cases need to decide if the information can be passed along to the manufacturers without impacting quotation submittal deadlines or if it can be addressed later. Generally, consideration is given to the quantity of changes and their impact on the quotation to determine which (if any) will be transmitted to the manufacturers. The user should understand that introducing changes while the quotations are being prepared can delay purchase of the machine and, consequently, have serious schedule impacts on the project. However, all known changes should be addressed prior to placement of an order. This can be accomplished by passing along changes to manufacturers during the quotation evaluation period or at a pre-award meeting with the selected manufacturer.

The purpose of the technical evaluation is to verify that the quoted scope of supply is in agreement with the specifications, to identify and remedy any significant differences in scope of supply, to identify and remedy any unacceptable deviations to the specifications and to access the significance of any technical differences among the quotations. The technical evaluation process should include a tabulation of quotations and an engineering evaluation of any significant differences. Tabulation forms should address significant quantifiable criteria. The user should be familiar with the expected tabulation format and identify any unusual criteria that needs to be added. Upon receipt of the quotations, the machinery engineer should check them for completeness and promptly address any obvious deficiencies. Dialog with the manufacturers is generally restricted during the evaluation period for all project team members and correspondence is written. While the manufacturers are addressing any deficiencies, the requisitioning engineer should begin tabulating information and reviewing and comparing manufacturer comments/exceptions to the specifications. The manufacturers' comments and exceptions should be reviewed for any cost options/standard arrangements that need to be addressed for conformance with the specifications. These comments/exceptions should be reviewed for comments that indicate that compliance with a requirement of the appropriate API Standard and/or a particular feature is available as an option. The user can assist in the review of comments/exceptions by identifying deviations from the specifications that have been accepted conditionally on previous orders. To avoid appearance of impropriety, some projects require that each manufacturer be fully evaluated and that meetings prior to order placement be avoided unless meetings are held with all manufacturers. In other cases, the technical evaluation is prepared without knowledge of the equipment costs. If the user elects to participate in the evaluation process, he should make arrangements when the quotations are received for a mutually acceptable plan to evaluate the quotations and avoid the temptation to introduce changes to the manufacturer's scope of supply and/or extend the evaluation into areas of interest that will not influence the technical evaluation of the quotations. Typical criteria for elimination/selection of quotations are:

- *The quotation was not responsive to the inquiry.* Elimination of a quotation from complete technical review because the manufacturer was not responsive should be considered only when the proposal requirements were clearly stated in the purchaser's request for quotations. Nonresponsive quotations could include failure to submit a quotation, a quotation taking general exception to the inquiry specifications, an incomplete quotation that is not supplemented with the missing information after several purchaser requests and within a reasonable amount of time.

- *The manufacturer failed to demonstrate satisfactory experience with similar units.*

- *Lowest total evaluated cost.* This cost is generally the sum of initial cost and the incremental cost of the power required to operate the machine. Caution should be exercised in using the differential power as a selection criteria because small increments in efficiency can result in large monetary differences. The efficiencies can be overstated in the quotation and unless a penalty is imposed in the purchase order, efficiency related deficiencies discovered during shop testing can nullify any benefits of the selection. Also, the monetary benefits are easily comprehended and makes selection on other basis more difficult.

- *Lowest initial cost.* This criteria for selection is used often. After all quotations are rationalized to a common scope of supply, the manufacturer whose quotation has the lowest initial cost is selected for purchase.

- *Significant machinery features favoring one manufacturer.* Selection on the basis or significant features should be restricted to differences that are of obvious benefit. Machinery trains without gears are generally favored over geared trains. Machinery units with minimum (capacity, critical speed, head, speed, power, etc.) margins beyond that required are generally considered less favorable. However, the value/risk of these features should be compared to the cost differential.

PURCHASE ORDER

After completion of the technical evaluation and receipt of project team approval a pre-award meeting is generally scheduled. This meeting may be with the selected manufacturer or in some cases, meetings may be held with more than one manufacturer. The purpose of this meeting is to verify that before a formal commitment is made, all manufacturer exceptions have been satisfactorily resolved and that the manufacturer is fully aware of his obligations regarding scope of supply, specifications and testing. Since work on the project has been progressing and the need for manufacturer documentation is becoming a high project priority, the project team usually expects the order to be placed as soon as possible after receipt of authorization. Nevertheless, an agenda should be prepared for the meeting and provided to the manufacturer allowing adequate time for preparation. Each engineering discipline on the project should be consulted for last minute changes/additions or clarifications. The technical agenda should include the following topics as a minimum:

- Review of the selected options to clarify the expected scope of supply
- Confirmation of the manufacturer's receipt of the applicable specifications
- Confirmation of the final disposition of all known manufacturer exceptions
- Review of the manufacturer's data provided in the quotation, adding missing information, and updating information to conform to last minute changes when necessary
- Review and finalize disposition of any manufacturer changes to the quotation
- Review of purchaser's post order inspection and expediting activities
- Confirmation of schedule dates for manufacturer's submittal of all manufacturer documentation requested in the request for quotation
- Establishment of tentative dates and level of manufacturer subsupplier participation for a coordination meeting

The owner's organization and engineering organization's attendance at the meeting should be limited to those directly involved in the specification, selection, and purchase of the machinery. The manufacturer's attendance should include representation from the factory order administration organization along with the local sales organization. In some cases, the driver manufacturer or other major subsupplier may be requested to participate on a limited basis. Emphasis during the meeting should be placed on issues that may have a cost, documentation submittal schedule, or manufacturing schedule impact. Any impacts and deadline dates for resolution of outstanding issues should be resolved at the meeting. Arrangements should also be made for subsequent technical audits if necessary and if the manufacturer has not already been advised. The user can facilitate the award of the order by utilizing direct access within the owner's project team for any information and/or clarifications needed.

The machinery engineer's next activity is to modify the requisition that was issued for quotation to reflect the agreed upon scope of supply. The revised requisition should be issued soon after authorization to proceed with commitment/purchase is received. It should include the following as a minimum:

- *Data sheets with manufacturer supplied data added.* Although the manufacturer may have been unable to provide fully completed data sheets, the data provided should be included on the data sheets since it reflects the manufacturer's quoted scope. The manufacturer may propose changes to these data in subsequent meetings and the proposed change can be compared to that on the data sheet. If the change is accepted, the data sheet should be revised accordingly and issued via a purchase order change.
- *Agreed upon manufacturer exceptions.* These exceptions are generally included as an amendment to the requisition or data sheets. Attempts to amend/modify the specifications to include the manufacturer's comments\exceptions can result in unique specifications for each machine. While this can be done, it can lead to a large number of project and equipment specific specifications.
- *Final predicted performance curves.* Inclusion in the requisition provides a single reference source for all predicted performance data and avoids confusion concerning the agreed upon performance at the time of shop testing and/or commissioning.

The requisition issued for purchase becomes a part of the purchase order—a contractual document with the manufacturer. The purchase order with the requisition will be the benchmark by which the manufacturer's documentation is reviewed, the machine is inspected in the manufacturer's shop, and the machine is accepted. In most cases, it must be revised periodically to reflect any agreed upon changes. Attempts to include meeting notes, references to the manufacturer's quotation, correspondence, etc. either by reference or by attachment should be avoided. Meeting notes and the quotation are usually difficult to modify and frequently include extraneous agreements that should not be included as a contractual requirement. Information contained in correspondence should be extract and located with the related subject(s) in the requisition or its attachments. It should be noted that both the machinery engineer along with the manufacturer can propose revisions to the purchaser's order. Changes should be minimized after an order has been placed, but, it is also the time on many projects when the engineering organization's design (piping, civil instrumentation, and electrical) activities peak and the manufacturer's engineering organization becomes familiar with the purchaser's requirements. Changes are inevitable as the project requirements and the machine design evolves, but it is not unusual for the engineering organization or the manufacturer to propose changes that compromise initial agreements. Therefore, the user should insist that he be formally informed of any proposed changes before the manufacturer is authorized to proceed with a change to the existing order.

A single machine for a project or similar machines for several projects may be purchased by the user. User purchase of large machines usually occurs for projects where the design, purchase, and construction of the remaining facilities can be accomplished in a relatively short period of time or where the owner's organization perceives an advantage in placing the order (i.e., a partnering agreement). At the time of order transfer to the engineering organization, the user should provide the following:

- Confirmation that all manufacturer exceptions to the requisition for quotation have been resolved and that the manufacturer is fully aware of his obligations regarding scope of supply, specification compliance, documentation requirements, shop testing, purchaser inspection and shipment.
- Confirmation that all requirements have been specified in sufficient detail that no substantial question remains that would delay manufacturer progress on the machinery order.
- The name of one manufacturer contact for engineering, inspection, and expediting throughout the purchase order.
- The quotation(s) of the selected manufacturer, all technical correspondence with the successful manufacturer, and a copy of

the purchase order and all referenced attachments reflecting the agreed upon scope of supply.

The effective technical administration of a user purchase order requires clear delineation of responsibilities and clearly defined lines of communication between the user, the engineering organization, and the manufacturer.

POST ORDER COORDINATION

After the requisition for purchase is issued, the machinery engineer's focus turns to satisfying the engineering organization's design disciplines' needs. The piping design group is usually the first to need information. This group establishes the location of the machine in reference to some benchmark (e.g., dimensional coordinates of a major nozzle). They also establish the pipe routing. Once the machine has been located the civil engineering/design group develops the foundation design. Each design group typically issues their design for approval and construction. A document not issued for construction typically can be revised (within limitations) without serious consequences. However, after a design document is prepared in the engineering organization and has been issued for construction, design work relative to that document and material fabrication is authorized to proceed. Changes to a document issued for construction can have significant consequences. With a foundation design issued for construction, the site construction group can begin installation of equipment and piping. However, the instrumentation design groups and electrical design groups continue development of the routing of conduit for site installation later in the construction period. Plastic models were the basis for reviews of piping, civil and electrical designs. However, with the proliferation of electronic tools, many of these reviews are being made via electronic models.

Almost concurrent with the manufacturer's preparation of documents to support the engineering of the plant, a coordination meeting is scheduled. The coordination meeting should be scheduled four to eight weeks after the commitment has been made and should generally take place at the office of the manufacturer having unit responsibility. The purpose of this meeting is to ensure that before a manufacturer commences engineering or fabrication, the purchaser's requirements have been specified in sufficient detail that no substantial question remains which would delay progress on the order or the project. The purchaser's machinery engineer should prepare an agenda at least two weeks in advance of the meeting. It should include the following topics as a minimum:

- Resolution of issues outstanding (if any) from the pre-award meeting
- Review of the applicable specifications and the exceptions accepted
- Review of the purchaser's data sheets attached to the order
- Review of advance copies of schematics
- Review of advance copies of outline drawings
- Discussion of testing requirements, inspection hold points, quality assurance, painting preparation for shipment and long term storage requirements
- Review of the manufacturer's submittal schedule for drawings and documentation

Two full days should be scheduled for the coordination meeting. However, this can be expected to extend longer depending on the number of attendees, the preparations made for the meeting and the complexity of the order. The purchaser's machinery engineer should chair the meeting and take the official notes to ensure that the information needed to continue plant design is documented in a timely manner. However, it is essential that the manufacturer's organization be aware of the purchaser's meeting expectations in advance of the meeting and have an opportunity to review and comment on the agenda before the meeting. A coordination meeting's success depends on both the manufacturer and the purchaser's machinery engineer being prepared to address the issues. The meeting should be attended by only the people whose expertise is needed. The agenda prepared prior to the meeting should be reviewed at the onset of the meeting for and last minute changes and a time allotted for discussion of each major subject. Distractions such as demonstrations, shop tours, etc., can be informative, but should be left to after the meeting unless they are directly applicable to issues (unfamiliarity with machinery, design features, etc.). The user should recognize the importance of complete and accurate manufacturer information needed to complete the project and avoid pursuing details that do not add value to the success of the project.

After the coordination meeting the machinery engineer is usually expected to review the documentation submitted by the manufacturer and coordinate any technical issues that remain after the coordination meeting or develop subsequent to the coordination meeting. The primary purpose of the manufacturer's documentation submittals is to provide sufficient information for the engineering and construction of the plant. THE PURPOSE IS NOT TO VERIFY COMPLIANCE WITH THE SPECIFICATIONS. However, the review of the information shown on drawings/documents will generally address certain areas of the specifications. Documents that are submitted and do not correctly reflect the specification requirements should be returned with comments and a separate dialog initiated with the manufacturer to address the deficiencies. The timely receipt of complete and accurate manufacturer documentation is as crucial to an engineering schedule as delivery of the equipment itself is to a construction schedule. For the engineering organization's effort to proceed on an orderly schedule, manufacturer drawings and data must be received on a timely basis from each vendor. These documents in a descending order of priority are:

- Advance issue with major connections dimensioned and foundation design information (if required)
- Documents required for manufacturer fabrication (e.g., welding, NDE, PWHT documents, etc.)
- Schematics or flow diagrams with components and instruments lists
- Machine analysis/studies and performance data
- Dimensioned outline drawings
- Wiring/interconnecting diagrams
- Data sheets, manuals, etc.

Since any delays in award of the purchase order for the machine, any changes delaying the manufacturer's preparation of documentation, and any manufacturer documentation schedule slippage become critical at this stage of a project, documentation review becomes a critical activity on many projects. Documents are rarely submitted in the above sequence and are usually missing some information thereby requiring resubmittal by the manufacturer. Since the project expects the manufacturer's submittal of all manufacturer documents as quickly as they can be prepared and the design disciplines are requesting information to fill unique needs as they develop, the machinery engineer is faced with an erratic and heavy work load. Changes introduced during the document review period usually create an additional complication to the machinery engineer and the project design disciplines, as well as the manufacturer. Purchaser and user comments on the manufacturer's documents do not usually constitute a change to the purchaser's purchase order nor do variances with the purchaser purchase order shown the manufacturer's documents constitute an authorization to change the purchase order. Likewise, comments on manufacturer documentation should not be in question form since the document is usually not the medium by which the manufacturer can reply. Each engineering organization will usually have procedures by which both purchaser and manufacturer changes and questions can be addressed. Examples of proper comment format for the manufacturer's documents are "change to .....," "add the following information....," "show the following....," "clarify the following....." The user should have participated in the activities preceding the manufacturer documentation submittal phase of the project and be prepared to minimize introducing requirements during this phase of the project that were not previously addressed.

The engineering organization's criteria for review of the manufacturer's documentation is as follows:

• Outline drawings for the main unit along with any free-standing ancillaries are generally reviewed for the following:

· Dimensions of mounting plates complete with diameter, number, and location of anchor bolt holes and thickness of metal through which bolts must pass.

· Locating or tie-in dimensions of the equipment relative to the baseplate anchor bolt holes.

· Identification, size, rating and location of every terminal connection to which the purchaser must connect. The terminal connections referred to above should include main suction and discharge nozzles, cooling water, lube oil, casing vents and drains, instrument and electrical connections. A complete tabular listing of all of the purchaser's connections shall be provided showing the connection symbol, the connection description, the disposition of the connection and the size of the connection.

· All horizontal and vertical clearances necessary for dismantling purposes with location of lifting lugs. (e.g., rotor withdrawal distance, filter removal, heater removal, exchanger bundle removal, etc.)

· Maintenance weights and name of part.

· Direction of rotation of each rotating element.

· Magnitude and direction of the expansion movement of main nozzles and the permitted piping forces and moments on the nozzles including thrust bearing and casing anchor point location.

· Exact total operating weight (with loading diagram). For most turbomachinery, data for dynamic analysis of the foundation is usually required and could include information such as:

· The weight of each major component with the dimensioned location of the center of gravity of each major component in three dimensional coordinates.

· The weight of each rotor with the dimensioned location of the center of gravity of each rotor in three dimensional coordinates.

· Maximum allowable eccentricity and maximum residual unbalance of rotors

· The location and magnitude of all static and dynamic loads (out-of-balance, surge loading, starting torque, etc.) transmitted to the foundation.

· Items embedded in the foundation should be fully detailed with the supplier clearly noted. The manufacturer shall provide the size and design details (and supplier if unique) of any preferred anchor bolts.

· Layout of structural elements requiring grouting, location of grout holes for each compartment, location of leveling, and jackscrews and recommendations for foundation/grout type. When epoxy type grout is to be used, the grouting surfaces shall be identified.

· Size and location of foundation cut-outs, if required, for downward nozzles and drains.

• Piping schematics (or flow diagrams) are generally reviewed for the final definition of the steady state and transient fluid flows, pipe and valve sizes, all instrumentation, valves, safety devices, and control schemes, winterization requirements, consistent identification of each terminal connection, symbology, and purchaser assigned instrument and equipment tag numbers.

• Bill of materials (components and instruments lists) are generally reviewed for all components and instruments shown on the schematics, the manufacturer and make/size/type of component with operating and design conditions and settings, relief valve sizing parameters, orifice sizes, set pressures, position of valves on failure, normal and rated power consumption, heat loads, design pressures/temperatures, minimum, normal and maximum pressures/temperatures, materials of construction, flows, alarm, and trip settings.

• Wiring diagrams are generally reviewed for a device list with ratings (if not included elsewhere on a bill-of-material), wire and terminal designations, terminal strip arrangement/numbering, operation of contacts, legend of graphic symbols indicating operating functions, required characteristics of control sources, terminal box enclosure, terminal box identification, etc.

• Logic diagrams are generally reviewed for manufacturer furnished controls indicating the control philosophy and the same device/terminal identification as used on the wiring diagrams.

Many manufacturer documents typically required are submitted for reference purposes and are not subjected to a detailed review/comment cycle (unless obvious deficiencies are noted). Examples of these type of documents are:

• *Performance Curves*—The predicted performance of the machines should have been finalized at the time of award, but no later than at the coordination meeting.

• *Cross Sectional Drawings*—The construction of the machine should have been reviewed at the time of award and again at the coordination meeting. Any issues with the manufacturer's standard construction should have been resolved prior to submittal of the drawings for the machine.

• *Test Procedures*—The requirements for testing should have been reviewed in detail at the coordination meeting and finalized at that time.

• *NDE and Test Reports*—The witness (if any) should have addressed concerns with the conduct of the test and the results at the time of the test. When test reports are formally submitted for review, the machine has been removed from the test area and assembly has proceeded.

• *Installation, Maintenance and Operating Manuals*—These items are generally provided at the time of shipment and are accepted as submitted. Unless the user identifies unique requirements for the manuals, the engineering organization will, in most cases, accept the manufacturer's standard manual.

Machinery technical audits/design reviews are generally reserved for individual components of a machine train (compressor, gear, driver oil system, sealing system, etc.). The purposes of an audit are to:

• Verify that the manufacturer understands all the expected requirements of the machine and has communicated these requirements to everyone involved in the order, including subsuppliers.

• Verify that the manufacturer has performed all of the necessary engineering for the machine and there are no unresolved issues pending.

As stated earlier, it is generally assumed that the engineering organization solicits quotations from manufacturers capable of building the machine needed and evaluates the manufacturer's experience during the technical evaluation of quotations. The engineering organization should recognize the need for machinery applications beyond existing designs. However, as the project develops, changes in operating conditions, machinery cost and schedule advantages, and other considerations can justify risks with designs with limited operating experience. If an audit is anticipated at the onset of a project, there is generally sufficient time to arrange for a rigorous and detailed audit. However, if the need for an audit is first recognized at the time of the technical evaluation, the user should be prepared to assist in developing the audit criteria and attend the audit.

SHOP TESTING

Since the review of manufacturer documentation can extend to completion of manufacturing, the requisitioning engineer usually participates in the shop testing of the machine. The user should expect to coordinate attendance at the tests with the engineering organization's representative, which may or may not be the machinery engineer having requisitioned the machine. It is generally expected that the user will witness the testing and evaluate the results of the tests with the engineering organization's representative. Although the user and other owner representatives may be well qualified in identifying potential problems areas in machine operation, they should resist directing the manufacturer to make machinery changes and avoid requesting additional manufacturer testing to study potential deficiencies at the time of testing. Directing the manufacturer to make changes in the hardware or testing can result in machine cost increases and delivery delays unacceptable to the project. By addressing these needs with the engineering organization, the project team's resources can usually minimize the project impact. Moreover, final acceptance of the tests and release of the machinery for shipment to the plant site is usually reserved for the engineering organization.

The user and the machinery engineer should review the test procedure prior to arriving at the manufacturer's shop to confirm (to the extent possible) that the procedure fulfills the requirements of the purchase order. The user and the machinery engineer should review the test procedure again with the manufacturer's testing organization to reach a mutual understanding of the test procedure and to get agreement that the requirements of the purchase order will be fulfilled. Any other deficiencies noted while witnessing the tests should be brought to the manufacturer's attention for resolution. Disputes concerning the results of the test and any other deficiencies noted should be fully discussed and resolution attempted. However, if resolution cannot be achieved at the time of testing both the user and the machinery engineer should refer the issue to the project for final resolution.

CONCLUSION

In summary, with a better understanding of the specification, quotation evaluation, purchase, post-order coordination and shop testing activities involved in the purchase of new turbomachinery, the user can identify the requirements early in the project and achieve a higher quality/lower cost installation.

APPENDIX

Centrifugal Compressors

- BEC 00TMC05 (Equipment Sound Levels)
  - BEC 76TMC01 (Plant Noise Control)
- BEC 00TMC20 (Pressure Casting Inspection)
  - BEC 00TMC21 (Welding and Weld Inspection for Pressure Containing Equipment)
- BEC 00TMC21 (Welding and Weld Inspection for Pressure Containing Equipment)
  - BEC 00TMC22 (Impact Requirements for Pressure Equipment)
    - BEC 12TMC01 (Pressure Vessel Design and Fabrication)
  - BEC 16TMC40 (Piping Fabrication, Erection, Inspection, and Testing)
- BEC 00TMC04 (General Engineering Requirements Equipment Purchases)
  - BEC 10TMC05 (Project Quality Assurance)
  - BEC 11TMC08 (Transport, Rigging and Erection of Equipment and Vessels)
  - BEC 90TMC01 (Purchasing Principles and Practices)
  - BEC 03TMC09 (Controls, Accounting and Auditing for Construction Projects)
- BEC 15TMC07 (General-Purpose Steam Turbines)-REFER TO SEPARATE TREE
- BEC 15TMC09 (Lube and Seal Oil Systems)-REFER TO SEPARATE TREE
- BEC 15TMC11 (Special-Purpose Gear Units)-REFER TO SEPARATE TREE
- BEC 15TMC13 (Special-Purpose Couplings)-REFER TO SEPARATE TREE
- BEC 16TMC22 (Process Equipment Piping)
  - BEC 00TMC04 (Winterizing and Heat Tracing)
  - BEC 00TMC05 (Equipment Sound Levels)
  - BEC 00TMC03 (Standard Details for Piping and Instrumentation Flow Diagrams)
  - BEC 01TMC01 (Design and Fabrication of Direct Fired Process Heaters)
  - BEC 12TMC01 (Pressure Vessel Design and Fabrication)
    - BEC 00TMC03 (External Loading Design Basis for Structures and Equipment)
    - BEC 00TMC21 (Welding and Weld Inspection for Pressure Containing Equipment)
    - BEC 00TMC22 (Pressure Equipment Impact Test Requirements)
    - BEC 00TMC25 (Positive Materials Identification)
      - BEC 16TMC05 (Color Coding for Metals Identification)
    - BEC 00TMC04 (General Purchasing Requirements for Equipment and Packaged Units)
    - BEC 12TMC21 (Fractionating Tower Trays and Internals)
    - BEC 16TMC30 (Selection and Application of Piping Components and Materials)
  - BEC 14TMC03 (Water Drawoff Arrangements for Oil Storage Tanks)
  - BEC 15TMC05 (Reciprocating Compressors)
  - BEC 16TMC01 (General Piping Design)
    - BEC 16TMC10 (Instruments Piping)
    - BEC 16TMC22 (Process Equipment Piping)
    - BEC 16TMC30 (Selection and Application of Piping Components and Materials)
    - BEC 16TMC40 (Piping Fabrication, Erection, Inspection, and Testing)
    - BEC 3TMC01 (Design and Fabrication of Steel Structures)
    - BEC 34TMC11 (Cold Service Thermal Insulation)
    - BEC 34TMC15 (General Fireproofing Requirements)
    - BEC 66TMC01 (Pressure Relief and Vapor Depressuring Systems)
    - BEC 72TMC05 (Plant Drainage and Sewer Systems)
    - BEC 10TMC40 (Corrosion Protection for Underground Steel Pipe)
    - BEC 11TMC01 (General Piping Design Requirements)
  - BEC 16TMC10 (Instrument Piping)
    - BEC 00TMC03 (Piping and Instrumentation Flow Diagram-Standard Details)
    - BEC 12TMC01 (Pressure Vessels Design and Fabrication)
    - BEC 16TMC22 (Process Equipment Piping)
  - BEC 16TMC30 (Selection and Application of Piping Components and Materials)

- BEC 16TMC01 (General Piping Design)
- BEC 16TMC05 (Color Coding Metals for Identification)

- BEC 16TMC22 (Process Equipment Piping)
- BEC 16TMC40 (Piping Fabrication, Erection, and Testing)
- BEC 32TMC17 (Pressure Relief Valves)
  - BEC 66TMC01 (Pressure Relief and Vapor Depressuring Systems)
- BEC 32TMC18 (Electric Motor Operated Valves)
- BEC 55TMC11 (Materials Application-HF Alkylation Units)
- BEC 10TMC40 (Corrosion Protection for Underground Piping)
- BEC 11TMC01 (General Piping Design Requirements)
- BEC 11TMC30 (Selection and Application of Piping Components and Materials)

- BEC 16TMC40 (Piping Fabrication, Erection, Inspection and Testing)
  - BEC 00TMC20 (Pressure Casting Inspection)
  - BEC 00TMC21 (Welding and Weld Inspection of Pressure Containing Equipment)
  - BEC 16TMC05 (Color Coding for Metals Identification)
  - BEC 16TMC30 (Selection and Application of Piping Components and Materials)
  - BEC 32TMC02 (Flow Instrumentation)
    - BEC 16TMC00 (General Piping Requirements)
    - BEC 32TMC01 (General Instrumentation Requirements)
  - BEC 72TMC01 (Segregation of Wastewaters)

  - BEC 32TMC15 (Heater Controls)
  - BEC 32TMC18 (Motor Operated Valves)
  - BEC 34TMC15 (General Fireproofing Requirements)
  - BEC 30TMC01 (Design of Plants to Facilitate Maintenance)
  - BEC 40TMC03 (Decoking of Direct Fired Process Heaters)
  - BEC 55TMC01 (Heavy Fuel Oil Systems)
  - BEC 62TMC06 (Fixed Fire Water Spray Systems)
  - BEC 62TMC09 (Fire Protection and Loss Prevention)
  - BEC 66TMC01 (Pressure Relief and Vapor Depressuring Systems)
  - BEC 66TMC04 (Draining of Flammable and Toxic Materials)
  - BEC 76TMC01 (Plant Sound Levels)
  - BEC 80TMC06 (Safety and Control Interlock Systems)
- BEC 32TMC11 (Alarms and Protective Systems)
  - BEC 32TMC01 (General Instrumentation Requirements)
  - BEC 32TMC13 (Wiring for Instruments and Computers)
  - BEC 58TMC05 (Supplemental Power Systems for Essential Electrical Loads)
  - BEC 62TMC09 (Fire Protection and Loss Prevention)
  - BEC 80TMC06 (Safety and Control Interlock Systems)
- BEC 32TMC09 (Induction Motors)-REFER TO SEPARATE TREE
- BEC 33TMC10 (Synchronous Motors)-REFER TO SEPARATE TREE