Our Philosophy on

Machine Design, Engineering and Development

of Prototype and one-off Machines or Production Systems

by Ted Stroud

During the process of designing, building and supplying a unique machine or system to a customer, there is a seemingly endless stream of decisions to be made.

These decisions involve safety regulations, environmental issues, legal concerns, and of course the design and engineering details, as well as the specifics of the machine's performance, its maintenance, its life cycle, operator training and other relevant interaction with the personnel concerned.

Depending upon the final destination, factors to be considered also include international law, local regulations, and the politics and culture of the countries involved.

Large or long range projects can be subject to a turn-over of personnel during the evolution of the integrated teams. It is necessary to maintain continuity through successive teams to ensure the smooth flow of any transitions and cross team collaborations during the design, development and building of a machine, as well as during the installation, commissioning and customer training.

As each assessment potentially effects each following decision to be made, and each conclusion is connected to, and has an effect upon other choices that follow, the reasoning for each decision and the results that are expected to be achieved should be recorded, along with subsequent changes that may be made as more data is collected. Out of these thousands of assessments and decisions, there are a vast number that would seem too insignificant to record, such as those that would just be the following of good design and engineering practice. However, the decisions which relate to the uniqueness of a prototype or a one-off machine should be clearly documented. These comprehensive records will serve well as a basis from which to trouble shoot and to further develop the specific areas where unforeseen problems arise. Complete and well maintained records are essential to ensuring that a continuously evolving team is able to easily see how the progressive steps of the planning, design and construction of the machine have developed to date.

The 'design team' may consist of a group working within a large corporation, or a small company which acquires the needed additional expertise on contract.

The 'customer' should be considered to consist of all of the people and entities involved in the acquisition of the machine or system, its operation, and the eventual maintenance that will follow once it is in place at its final destination.

The pressure on industrial machinery manufacturers is ever increasing and machinery builders continually strive to respond to their customers' demands for faster, more versatile, reliable, durable and operator friendly machinery that has the flexibility to produce a wider range of products with little or no set-up, while meeting stringent safety standards and requiring minimal maintenance. At the same time, the end users also expect a lower capital cost that will provide a greater return on investment, in addition to their demand for machinery and processes that are "green".

In pursuing this versatility and economy, machinery manufacturers must keep abreast of, and incorporate into their designs, the latest technology with which to: gain greater control over precise product quality; increase productivity; and reduce waste and scrap, while trying to protect the environment.

The multidisciplinary ensemble of engineering talent necessary to undertake a large machine/system design and build project will require: research and development management skills; familiarity with the technologies expected to be incorporated; CAD design and engineering expertise in each of the disciplines involved; CAM software programming proficiency; skills with electrical and electronic design software to run and debug the drive and control system design before it becomes a physical reality; and expertise in document management systems to handle the entire project.

A one-off machine, or prototype, will most likely require some modifications before it reaches its productive potential. Mistakes will occur, better ideas will flow and the design team needs to be flexible and adaptable, and easily alter course as new data becomes available. As early as possible, some animation should be run on a 3D solid model of each of the critical areas to accomplish some initial debugging.

It can be quite risky to release manufacturing drawings before all of the drawings have been completed and checked, at least for a given assembly. If the timeline is such that it is found that some drawings for some assemblies must be released for manufacture before others have been completed, the designer must recognize the possibility that important points and interconnections may be missed which could create unnecessary problems and costs.

It is essential that the design team work closely with the customer during the development of the concept and the acceptance criteria, which at that point should detail all that the machine is intended to achieve: productive rate; target efficiency; quality and precision of the intended product; and other data including the expected costs, all of which would provide an overview of the technical hurdles to be overcome in the output of saleable product.

A well designed machine or system should easily meet the performance goals as described in the design criteria for: productive output in both quantity and quality; ease of operability; safety standards; overall efficiency; savings in material costs; lower labor costs; durability; reduced impact on the environment; lower energy consumption; utilization of less floor space; and minimal waste and scrap.

Unlike mass-produced machinery and equipment, custom one-off specialty machines do not warrant their manufacturer investing in expensive, unique tooling or dedicated machinery to produce just one particular machine, and there is little or no economy in maintaining a large spare parts inventory, except for the very specialized components. Wherever possible, one-off specialty machines or systems should be designed to take the best economic advantage of the available common materials and sizes, including standard commercially available components.

Because the engineering is amortized over just one machine, a custom machine is far more expensive to build than a mass produced machine. However, a custom special purpose machine can provide the end user with a definite advantage over their competitors, as well as a more economical solution to manufacturing specialty products.

Before the designing begins, a feasibility study should have been conducted, which would include all available technical information and operational expectations relating to the intended results or product. It is important that the marketing, sales and engineering personnel, and the customer fully understand the legal and ethical ramifications of the use of whatever chemicals or dangerous materials that may be involved, if any. It is also the responsibility of the design team to look for alternatives that will reduce the inherent risks and potential impact on the environment. Likewise, it is a further responsibility of the design team to understand the legal implications for their organization as a manufacturer producing such a machine where dangerous goods and chemicals may be involved, and to apprise their customer of the risks and proceed with due regard.

The feasibility study should have determined all relevant criteria including the degree of quality of the output and the life of the machine over which it can be sustained. If a new specialty product is intended, with no machine or system on the market to produce such, then a custom special purpose machine may be the only option.

A preliminary proposal should then be developed to determine if all of the criteria can be met or what percentage can most likely be achieved. This will probably include some basic pre-engineering, which will be necessary to determine if the targets are within the achievable range. It should have been confirmed by this point whether suitable standard commercially available machinery can be purchased to meet the needs, if available machinery can be suitably modified to fill the requirements or if it is indeed necessary to design and build a custom special purpose machine to satisfy the demands of the market. The refurbishment, modification and reconfiguration of a used machine or system might also be an alternative.

Regardless of the conclusions of the foregoing, the next step would be to develop a detailed proposal for either the required custom equipment or for the standard commercially available machine, complete with cost estimates and firm pricing for any modifications that may be required along with documentation for the rationalization.

Regular interim reviews should be conducted throughout the process of developing the detailed proposal so that corrections in the course can be made with minimal cost.

During the proposal phase it will be necessary to determine the amount of space required to accommodate: the machinery or system, the necessary support equipment, the storage of raw materials, and the finished product; and whether indoor or outdoor. Besides the physical dimensions of the machine or system, locations of openings such as doorways, windows, ventilation, etc., and services such as heating system, electrical power, overhead power line clearance, location of buried power cables, natural gas supply, propane gas storage and supply, water supply, sewage disposal, telephone cables, radio transmission towers, shipping and receiving areas, unloading capabilities, highway and roadway capacities and access points, railway sidings, possible airport services and plant security, either existing or planned should be included.

After it has been demonstrated that the project is both economically and physically feasible, and the proposal submitted to, and approved by the customer, the machine design engineer can now turn his/her main attention to the design of the machine or system. There should be customer input throughout the design process and it should always be considered valuable.

The machine designer, more than ever, has a need to continually further develop his/her techniques using the latest design software and methods, and to integrate the most versatile control technology into the machine. It is essential to have frequent design reviews, with separate reviews to include the customer, all of which must include the scheduled targets.

The level of advanced technology incorporated into a machine is critical; too much sophistication can unnecessarily increase the capital, training and operational costs, while too little can also result in higher operating costs.

Whether the machine or system is for an outside customer or whether it is an internal project and the customer is your employer, these steps should be taken equally seriously.

Even though the civil and architectural engineering teams will be responsible for determining the geological conditions and researching the history of the site to determine if there are any previous land fills, excavations, foundations, cavities such as disused sewers or other types of tunnels used for a previous industry, buried toxic wastes or forgotten cemeteries, the designer should be aware of these data which have been uncovered. In some locales there is the possibility of archaeological finds, which may impact the time line for the construction of foundations, etc. The depth of soil over rock, water table or other underground conditions should be determined, and if any pits or whether underground services may be required. Factors introduced by wind, seasonal conditions including temperature and humidity variations, altitude and other variable climatic and environmental conditions should also be noted.

Besides the essentials of machine design, a very important point that a machine designer should keep in mind are the dimensions of the available sea-going shipping containers, or other conveyance, their weight capacities and the available configurations. If roads over which the containers will be transported include switch-backs in mountainous areas, or if the unloading space at the final destination is limited, then it may be necessary to use only 20 foot containers. Whatever transportation equipment is to be selected, the machine sections or subassemblies must fit into or onto the conveyance.

It is not unusual for something unforeseen to happen where local machine shops and/or other services are urgently needed to keep the installation on schedule. Contingency plans should be developed during the design phase to address these unique needs. These plans should include the names of the organizations and their proximity to the installation and the names of those who may be called upon in case of these eventualities. It would be prudent to make arrangements for their services ahead of time.

It would also be wise to determine, in the event that unions are involved, the ground rules for a good relationship with the unions.

Designing prototype or one-off production machinery, that will function as expected from the start-up/commissioning through the intended working life of the machine or system, requires a great deal of thoughtful research and development and careful long range planning. The design engineer and his/her team only get one shot at this machine or system and it must achieve the intended results, with no retries – a bit like a moon shot, in fact for some projects it may be just that. This can be very challenging, but can also be very rewarding in financial terms for both the customer and the company creating the machinery or system. A successful project can also be very inspirational for the machine manufacturer's team and can be very satisfying for all those involved and who have contributed to the success of the project.

In beginning a comprehensive machine design project, one should first develop a list of the required parameters, in detail, with a sub list of additional features and/or attributes that would be desired by the customer, but which might not necessarily be included in the finished piece of equipment, the inclusion of which would have the potential to positively influence the creative thinking of the design team.

The quality and precision of the output of the machine, and the standards of the materials to be incorporated into the product during the production process, are factors that must be considered early in the design process. A component's utility will largely dictate the tolerances to be specified for a particular application. The designer should understand the effect of tolerances on the quality of the product to be produced as well as how tolerances impact the manufacturing costs.

As well, the monitoring and testing equipment to be used in conjunction with, or incorporated into, the production machine or system must be commensurate with the required precision. In addition, the life and total anticipated number of product units or the number of cycles must be included in the calculations to ensure that the machine will remain efficient, reliable and accurate throughout its intended life and that it will yield the expected return on investment.

The aesthetics as well as ergonomics are important. Human interaction with a machine should be easy and comfortable. When a machine or system is easy to operate and is pleasing to the eye, the operators/crew will have more respect for the equipment than if it were an ugly difficult beast; the owners will also have more confidence in the machine. The appearance of the machine can also impress the customers, either positively or negatively. It should also be kept in mind that operators or crews who are dissatisfied with a machine, or system, will not be as productive as they would be otherwise and therefore the machine will probably not perform as intended. They will be less than dedicated in working to overcome even small difficulties. Conversely, if the crew likes the machine or system, then it should perform as expected, or better, due in large part to their dedication to overcoming the problems that arise.

A scope of work, as detailed as it can be at this point, should be included for each of the phases of the project. A target completion date should be established, with the projected steps being developed backward from the completion date. If the accumulation of the various steps is allowed to determine the completion date, there is greater risk that the project will be late and therefore likely to be over budget. Even though there is often great uncertainty and risk in designing and building custom, one-off machinery or systems, custom designed equipment can be created, and be up and running, on schedule and on budget. However, the time-line and the budget must be very tightly managed.

The project should be divided into sections or areas of responsibility with the areas of the most uncertainty, which carry the greatest risk, being confronted first. Often secondary steps cannot be contemplated until some basic answers or solutions have been found through some research and development.

The individual designers should have a thorough knowledge of the various machining and manufacturing processes and should be familiar with assembly procedures as well as the operational characteristics of manufacturing machines in the target industry.

Where the results would be suitable, all custom components should be designed to be machined with the available tooling on the company's premises, with the company's standard fleet of machine tools and processes which are normally used within the company, using standard size and readily available materials where possible. Special processes that require long lead times should be avoided unless the desired results would not otherwise be achievable. Additive manufacturing (3D printing) should be considered for some intricate parts; in fact to achieve the necessary geometry for a part's particular function, additive manufacturing may be the only viable option.

When a machine is designed and engineered for mass production, it is necessary to calculate the strengths and lives of most, if not all, of its components to ensure against designing more capacity, life or attributes into the piece of equipment than necessary, which would thereby add to the final costs. At the same time the design must produce a safe and predictable piece of equipment with a life range that meets the decided criteria.

This is also important with custom one-off machines or systems. However, it should be kept in mind that when manufacturing single parts or low quantities, it would be easy for the designer to use up potential cost savings, and more, through intensive design effort while attempting to achieve a point just above the minimum specified performance requirements. Also, the cost overruns on an accumulation of individual minor components can easily destroy a budget.

Thorough calculations should be performed for all critical features and/or elements within each component, sub-assembly or assembly, even though a design engineer may be experienced enough to select the appropriate sizes through visualization. The criteria and rationale should be recorded in notes, no matter how limited, to allow subsequent members of the design team to follow and understand the rationale of each aspect of the design and for the notes to aid in easier analysis should some redesign be deemed beneficial.

An important part of a machine design engineer's experience is the first hand observation of: the circuitous route encountered by the purchasers to source materials; the problems encountered by the machinists during the manufacture of parts; the difficulties experienced by the millwrights in assembling a machine; the crating and logistical nightmares of the shipper; the communications labyrinth and local resource obstacles faced by the field engineers, the challenges faced by the operating crew as they master a new and unfamiliar machine/system/process, and the demands on the maintenance crews. To have some hands on experience is even better.

Design errors can be difficult to see, especially after further detail has been added. Keeping adequate records will help ensure that errors and potential problems will be easier to detect and remedy.

Resolve any design discrepancies early. Remember the (old) adage: it costs $10 to correct on the 'drawing board', $100 to fix on the shop floor and $1,000 to rectify in the field.