APPLIED SCIENCE AS IT AFFECTS OUR ENGINEERING*

W. H. Radford**

THE CATERPILLAR Tractor Company is glad to have the opportunity of participating in this meeting and appreciates the honor of presenting its conception of physics requirements for the young engineer who wishes to associate himself with its type of industry. It does not presume to judge of requirements in other industries, and it believes that in order to complete the picture certain other requirements should be discussed which make for success or failure and which are not necessarily attainable in college training.

The Company has asked me to present this paper because training of men is a subject very close to my heart, and not because I possess any outstanding ability as an orator. I shall try to be constructive in any suggestion I may offer, and I trust you will so regard those suggestions. Standing before this representative audience of professors and physicists today, there is just an indication on my forehead of the cold beads of perspiration which, in college days, stood out in profusion when I entered the presence of the professor with my assignment badly prepared. I may deviate from the technical limitations implied in the title of this paper, but I shall try to present this subject on a practical basis.

We have then to consider the training of engineers for an industry embracing the design, manufacture, sale, and use of engines, power units, tractors, road machinery, and associated equipment. This is a rather broad line to cover. It requires knowledge in several branches of engineering—mechanical for the application of physics to design of prime movers and the devices for transmission and application of power; metallurgical for the characteristics and treatment of metals from ore to finished product; chemical for composition of ferrous and non-ferrous alloys, fuels, lubricants, and gases; electrical for design and application of motors, generators, and instruments; civil in earth moving, road building, and excavation; agricultural for soil characteristics, soil working, terracing, planting, cultivating, and harvesting. There are others, but these will suffice to indicate the range of application.

Efforts to make improvements, changes in, and additions to our industry's products to fit them for an ever increasing number of uses may easily end in chaos if the development disregards the basic laws of physics. Because of the wide range of products in our industry, the development must be orderly, with a personnel trained in fundamentals, cooperation, and due respect for a wisely applied pinch of the salt of experience.

If we visualize the plan of industry from the doorway of the basic laws of physics, we will recognize how engineering has applied those laws. The production application of the laws will be reflected in the design, fabrication, assembly, and operation of the products. The maintenance of uniformity in the product from the standpoint of performance will be the result of physics applied in the measurement of power, efficiency and routine commercial testing. More distantly revealed in the product and its standards of performance will be the phases of development by physical laws applied in experimentation and commercial and fundamental research. Through sales and service to its useful work for mankind there still will follow some need of those same fundamental laws.

Out in front of this picture are the challenges which urge us on to greater and greater efforts to produce better materials and methods with which to increase efficiency and produce longer product life. We can design better power plants and machinery when we have materials which will withstand stresses

* Paper presented before the Physics Teachers of Illinois, meeting concurrently with the Academy of Science. The Academy Committee on Publications considered it important enough to print for the benefit of the general membership.

** Assistant Chief Engineer, Caterpillar Tractor Company.

of 1500 lb. at 900° temperature; when we know how to produce perfect combustion of fuel; when lubricants will not break down at 350°; when we lessen the distortion of metals under heat; when dust and dirt can be entirely excluded; when we can make non-lubricating surfaces more resistant to wear; when we can eliminate corrosion; when we can automatically dispose of the products of ordinary use and wear. The list is endless and the ultimate is a product which a fool cannot harm.

Let us now review some more concrete examples of the engineering application of physics in our industry. The design of the product involves probably more of the comprehensive field of engineering physics than any other phase of the business in calculation, computation, and reasoning.

The entire field of statics is covered in the use of force diagrams, moments, couples, centers, and equilibrium in the design of gear teeth, flywheels, clutch level linkage, connecting rod sections, track roller frames, motor grader frames, tractor frames, power unit frames, track shoe grouser placement, general tractor, motor grader, and power unit proportions, center of draft, articulation of track trucks, etc.

For consideration of bodies in motion, we find that knowledge of the fundamentals of dynamics, recognized by the familiar "Force=Mass times Acceleration" equation, plays a most important part in design problems—forces in pistons, connecting rods and reciprocating assemblies; in springs and assemblies they actuate; in flywheels, gear trains, tracks, and all rotating masses; in frequencies of springs and dampening of harmonics and surges; in moving oil columns in lubricating systems and fuel lines; in tortional vibration in crankshafts; in losses through clutches, brakes, piston and rings, oil seals, belts, and other results of friction; in balancing tractors, graders, and other machines so that they can operate without failure at various angles and positions; in momentum of flywheels, gear trains, vibration dampers, and of entire machine assembly; in determination of impact loads by spring operated assemblies and supporting sections, or by operation of machines over all kinds of terrain and at various speeds; in hundreds of other examples of the engineer's ordinary bread and butter.

In dealing with solids we must know about modulus of elasticity, yield point, ultimate strength, ductility, hardenability, erosion and corrosion resistance, fatigue, and other properties of materials; the hysteresis and dampening effect of rubber or synthetic rubber compounds; the specific gravity and density of materials so that the wisest selection of materials can be made which embraces the required qualities.

A knowledge of the physical properties of liquids is necessary to make any intelligent use of their applications. This subject is very often neglected. One must know such properties as surface tension and its effect on oil adhesion, thickness of oil films, lubrication properties of oils and fuels, action of oil columns under pressure, weight and specific heat of fuels such as gasoline and kerosene for the design of hot or cold manifolds, effect of restriction and change of sections on moving liquids in cooling, lubricating, and fuel systems.

Properties and effects of air and gases at rest and in motion under heat and pressure sometimes challenge the physicist's knowledge. For the cycles in engines, Boyle's and Charles' laws are still fundamental and simple but not so easy are the problems involved in getting air or mixtures into engine cylinders; in calculating attendant friction losses and the temperature rise and heat transfer through air or gas; in designing manifolding and combustion chambers; in designing radiators and fans, and more recently superchargers for restoring power lost by altitude operation; in the action of gas and air moving together to cause vaporization or atomization of fuel as in carburetion or injection equipment.

The branch of physics dealing with various wave motions and wave phenomena has a definite use in locating noise which is the result of periodic motion in machinery, longitudinal and transverse waves in air, combustion and injection pressure waves, wave motion in steel sheets and other construction members, including large castings. A knowledge of the detection of such motion affords the opportunity to apply corrective measures for this class of defect which very often cannot be foreseen in original design. These laws of wave motion apply in the design of crankshafts, gear trains, fluid flow in injection apparatus, to prevent destructive forces.

In the realm of heat is required familiarity with boiling and freezing temperatures of liquids for cooling systems, knowledge of heat transfer from surfaces, and the coefficients of heat transfer in materials which vitally affect piston and piston ring design and thickness of cylinder walls and engine cooling cavitation. The coefficients of thermal expansion are important in designing for proper clearances in valve trains, clutches, bearings, and similar problems. Specific heats are used to determine the amount of coolants which must be circulated by pumps.

The fundamental laws of electricity and magnetism are used in the design of magnetos, generators, and starting motors; of simple lighting and wiring diagrams used at times in tractor and motor grader lighting; of switch board control for engine-generating units or special electrical apparatus for carrying on tests of engine generator products. Knowledge is necessary of the principles of operation, the limitations and the sizes of direct and alternating generators and motors.

A different collection of fundamentals could be cited from a knowledge of the requirements demanded by the manufacturing phase of the industry. Manufacture which includes fabrication, processing, and assembling deals with forces required to operate stamping, forging, pressing, and mechanical advantage machines. It deals with aids which eliminate inconsistencies in assembly such as definite length of leverage wrenches and direct torque reading wrenches for stressing assemblies to a predetermined load. The laws of gravity and friction are used in arrangements which transport material from place to place. The expansion and contraction of parts with proper application of heat are commonly and widely used in assembly of bearings, valve seat inserts, and other tightly fitted parts. Necessary is the knowledge of cutting oil viscosities, oiliness and cooling properties in lubricants used with cutting tools; of properties of compressed air as a source of power for assembly tools; of hydraulics used in drives and controls for machines; of temperature control for maintaining precise measurements of related high precision parts and equipment; of the laws of conservation of energy which are important in the efficiency of equipment and personnel and are usually translated to read, "Maximum work with minimum effort." Knowledge of electricity and magnetism in the manufacturing phase is useful for various reasons. Magnetic holding and lifting devices speed up quality work. Electrostatic air filtering systems for cleaning dusty places are widely used. Problems of resistance heating in heat treating equipment, and the use of resistors and capacitors in the control of such devices have been applied for a long time and are being extended to induction heating and quenching processes for selective hardening in crankshaft bearings and many other parts. Inspection makes use of X-ray machines and magnaflux to determine soundness of castings or important stress members.

In foundry work we must know the fusion points of sand and metals; the means of elimination of physical impurities by gravity such as in slag removal; the placement of risers in the mold; the direction and velocity of flow of molten metal; the materials which, when mixed with others under certain conditions of heat or atmosphere will give required properties to the mix.

In plant engineering we are concerned with the construction of plant building; with heating and ventilating of buildings involving movement of large volumes of air; with cooling and exhausting fans for conditioning air in offices, paint shops, carpenter shops and foundry; with the entrainment of water in air streams under high pressure for cleaning and washing processes; with the mounting of high speed and precision machine equipment to eliminate vibration or to isolate from disturbing vibrations; with elimination of objectionable noises and with improvement of illumination for increased safety and accuracy.

In the testing of materials and the products, one needs to know the physics employed by a wide range of testing machines and instruments. Tractors and motor graders will use field traction dynamometers or will move dirt or some kind of equipment. Engines and power units will be hooked up to hydraulic or electric dynamometers or other power absorption units. Materials will demand the use of tensile, torsion, compression and impact machines.

In the field of other instrumentation, the engineer will encounter the use of the stroboscope for arresting motion to study moving parts; of the piezo-electric properties of crystals in producing currents when under pressure; of heat measuring instruments such as calorimeters, thermocouples, pyrometers, and fusible materials; of cathode ray oscillograph in combustion studies, torsional vibration and spring surge; of vibration pickups used with the oscillographs for torsional and other vibration tests; of photo-electric cells for controls and density detection; of the properties of condensers, radio circuits, vacuum tubes, instruments for measuring sound levels, microphones used with the oscillograph for measuring sound frequencies; of lenses and optical equipment such as cameras, projectors, telescopes, microscopes; of polarized light and its application to the examination of stresses in photo-elastic materials; of optical flats and profilometers for measuring the degree of perfection of surfaces; of many other instruments which I haven't time to mention.

For the research and development fields of the industry, fundamental work is going on in fuel injection equipment involving hydraulic and mechanical stress, strength and fatigue of materials; in the thermodynamic analysis of engine combustion efficiency; in sound frequencies of gases producing combustion detonation; in fuel spray penetration, drop size and velocity; in the ignition quality and power producing qualities of fuels; in the problems of compounding lubricating oils; in the hysteresis effects of rubber and steel; in the properties of bearings for low coefficients of friction, higher melting points, and greater load capacity. The list is endless.

Now that I have made a necessarily dry recital of some of the technical requirements in our industry, let us consider the personal element factor in the problem and the means at hand for selecting young physicists and placing them in industry where they can best serve themselves and their employers.

I believe that a comparatively small percentage of engineering graduates are temperamentally fitted to compete in a large industry, and there are others who seem unable to acquire a liberal knowledge no matter what the educational opportunities may be. But whatever knowledge is absorbed helps to place the recipient in a better position to make at least a degree of success in life.

Some people claim that an engineering education is wasted on most young men. I cannot agree with this extreme view. I believe that engineering offers one of the best preparations in logical thinking for any kind of business or walk of life. As in any other profession, not all can reach the top, but there are many nitches to fill in industries of various magnitudes. One great service our educational institutions can give to the young man and to industry is to help him to select a level that is compatible with his inherent ability, and to teach him to be satisfied with the degree of success which such a level can give. The man of only average ability should not be placed in a large industry where competition of other men will submerge him. He should be placed where he can have more time to develop, or where the ultimate goal is less difficult to reach.

We too often find young college men imbued with an exaggerated idea of their value to industry, and it is rather difficult at times to impress them with the fact that industry is making an investment in them on which it cannot expect returns for several years. On the other hand, to work through that period before industry sees the returns is the toughest part of a young engineer's career, and what a tragic disappointment it is to him if he has selected an industry which does not recognize when the time has arrived to pay him dividends on the returns. Here again colleges can give good advice to the young engineer for estimating his own value and for making his choice of a career with a fair dealing industry. We believe we are a fair dealing organization.

In selecting young engineers for our organization, we try to choose those who will be able to advance and grow as we grow; those who show evidence of intelligence, vision, and ability; those who have promise of carrying on when we are no longer able; those who appear trustworthy and have commanded the respect of teachers and fellow students.

We stress the value of a high academic rating and of accomplishment in a chosen course as being an indication of expected rapid development. We regard participation in extra curricular activities as indication that there is a natural liking for others and that leadership will result. We feel certain that contribution to the expense of education brings earlier maturity, better sense of values, and a surer foundation on which to place responsibility.

We inquire into the young man's pleasures, hobbies, and means of recreation, and family life. Every young man must learn how to work, and he should know how to play. Only happy men can attain the highest accomplishment.

Because our industry embraces many branches of physics and engineering, we want men who are broadly and thoroughly grounded in as many fundamentals as possible. We require knowledge in civil, mechanical, electrical, metallurgical, chemical, agricultural engineering, and the application of these branches overlap in design and use of many of our products. The important thing is that we have men who have been taught how to think and organize their thoughts, and where and how to look for information. This may be an age of specialists, but a young engineer just graduating is in no position to choose a highly specialized line. It narrows his opportunity while he is young and prevents a possible wiser choice later on when he has had a chance to get a broader view of the work which industry has to do. Our experience shows that his preferences for certain lines of work rapidly change during the two years of his training. These lines of work may not be what we choose to call strictly engineering. They may include sales, service, purchasing, or other lines for which he may develop aptitude, but which will probably require training in the engineering department beyond his two year period. It is essential that he have no preconceived ideas of a definite path of advancement. Such advancement must be left to our judgment.

Entering our training course should be regarded as a further opportunity for education and not as a probational period to be endured while the world is anxiously waiting to be turned upside down. The engineer in training should study the products and methods of manufacture which he encounters and attempt to interpret them in terms of what he has learned in college. If he conscientiously tries to do this he will soon discover that the compromises which have to be made with the pure dictates of physics in producing a product which is saleable and which will satisfactorily serve mankind, require a knowledge of the application of physics which cannot easily be attained in academic training. These compromises are the unpredictable headaches which accumulate to make for experience. Nothing in a young engineer's training can make up for that experience, and it is best he learn early in his career that the gray hairs in the chief engineer's head are an indication of tough problems solved and not a proof that senility is submerging his knowledge of physics and its application to the work at hand.

With the thought in mind that the period of training in industry is very definitely an opportunity to gain further knowledge, the graduate must apply himself diligently to work immediately before him. It means hard work, but work for which he is being paid. That present job in front of him must be the most important thing on his mind. There is nothing he can do about what is past. He cannot take the time to dream about the future, which must always be more or less obscure, for time so spent does not register with a training supervisor. The job at hand conscientiously and enthusiastically done is the only road to future success. Now the job at hand is very often not a pleasant one, for we expect him to learn to use his hands as well as his head, and those hands are sure to be initiated into dirt and grime; but still the necessity exists for knowledge of how dust, dirt, grime, and other adverse agencies affect the fabrication and successful use of our products.

To do his work day by day, he must cooperate with those with whom he comes in contact. Cooperation of many individuals is the foundation on which successful industry is built. A lone wolf hasn't a chance, and a lone wolf engineer in training endeavoring to show authority and superiority soon finds barriers which he is not able to cross alone and realizes too late that by his attitude he has placed himself in a position where fellow workers or supervisors cannot help him. There are plenty of men who seek authority. There are comparatively few who are willing to assume the responsibility, which comes from taking the hard knocks and accepting the challenge of problems involved in fitting themselves into a large organization. Once prepared to take responsibility, they will find that the necessary authority naturally follows, and opportunities for constructive changes become the ordinary every day work.

During two years of training, our young engineer must not only become familiar with the materials we use and how they are processed, assembled, and tested, but also how to conduct himself in his personal contacts. It is essential that he learn the languages of all from sweeper to president, for problems will be put before him in all those languages. His will be the task of interpretation in terms of engineering or applied physics in order to solve those problems.

In conclusion, I wish to say that our educational institutions are doing an excellent job of training, considering that many of them have inadequate equipment and personnel. Industry cannot expect them to solve its problems, but it does expect them to make a thorough job of teaching a broad range of fundamentals.

I wish to acknowledge the help given me by our young graduate trained engineers in the preparation of lists of physics requirements in this paper.