Technology of efficient energy utilization

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MOTION

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General Considerations

The Group was given to understand that its assignment comprised transport of goods and people and the shaping of materials (e.g. forming, joining, cutting). Since, however, its subject title was Motion, consideration was also given to those aspects of industrial processes in which movement was being imparted to the materials being processed.

Energy utilization statistics were available mainly for US transport (e.g. E. Hirst and J.C. Moyers, "Science", *179/1299* and R.Q. Rice, International Automotive Engineering Congress, January 1973, S.A.E. 730066), but there was a paucity of data on European transport and on the industrial processes. The Group enters a plea for an extensive energy utilisation data base for the field under examination as an essential ingredient of the drive for energy economy.

I. Transport

Since between $\frac{1}{4}$ and $\frac{1}{5}$ of the total energy budget in the US is absorbed by transport (the figure is about $\frac{1}{6}$ for the countries of the European Economic Community), and this sector exhibits the fastest growth rate, all measures to reverse or at least to arrest this trend are desirable. Whilst the Group could see many opportunities for this being achieved through technical improvements, it is convinced that, besides the use of smaller cars, better organization and management of transport and traffic offer the most immediate and probably most cost-effective possibilities. The Group also wishes to draw attention to the desirability of fostering developments in communication technology to help eliminate some of the present demand for travel.

The energy consumed in the manufacture of transport equipment probably amounts to 10% of the energy expended in transportation (based on average car lifetime in conditions typical of the U.S.A.) and efforts to make the equipment more durable seem distinctly worthwhile. Dr. Massar calculates, for example, that (in conditions more typical for Europe) a 20% increase in the life of cars could save up to 5% of the total transport energy requirements. A similar effect would result from a decrease in the size of cars and a simplification of car equipment.

Air transport consumes by far the largest amount of energy per passenger (or freight ton) mile, followed by car and lorry, and railways, pipelines and public transport buses (at a stipulated average passenger occupancy) are the most economic means of passenger travel and freight transport. Everything should therefore be done to shift the present distribution of use of the different modes of transport towards the more energy efficient ones. For example, Dr. Massar estimates that transferring 50% of the transport of freight by road to goods trains saves 17% of the total energy consumption attributable to transport. Accordingly, the Group examined what part technological developments could play in bringing about this shift in the distribution of the use of different modes of transport, and so reversing the historical trend. Its conclusions are stated below.

A. Road to Rail

The main virtue of road transport springs from the flexibility and comfort of car and lorry. Accordingly, development is called for in the following areas:

in regard to urban passenger transport —

- provide far more frequent trains and buses with more stopping places and greater passenger comfort;
- develop moving walkways, perhaps aerial rope chair lifts in order to link up homes and shops with subway and overground commuter trains;

in regard to urban freight transport —

- further development of over or underground pipelines to link up rail depots with local pick-up and delivery points;

in regard to inter-city transport —

- improve roll-on and off of cars from car ferry trains;
- develop dual purpose freight vehicles to run on either road or track;
- develop an extra low-cost car, taking advantage of the fact that it would spend much of its time riding on trains.

B. Air transport will continue to be the preferred mode for intercontinental and trans-maritime journeys, (it is many times more energy efficient than seagoing passenger transport). Although reduction of air speeds would be the most powerful means of improving energy utilization, the flight time will continue to dominate passenger choice. Research into more economical engines is the only feasible recommendation (e.g. plasma jet with leaner mixtures in gas turbines).

For short and middeldistance overland passenger travel, the new fast trains already have the edge on airplanes. For the longer distances magnetic levitation with linear motor propulsion, whilst comparable with STOL (short take-off and landing) aircraft in terms of energy efficiency, has the advantage of greater capacity and more convenient terminal points. Its development should therefore be fostered, especially for very high speed applications in partially evacuated tunnels, further enhancing its overall efficiency.

C. Ships are a relatively efficient means of trans-maritime freight transport, but improvements may be worth obtaining by developing freighter submarines or even airships, on account of their lower resistance to motion. All three are also suitable for nuclear propulsion.

D. Prime Movers

The engines of transport vehicles, especially of short distance rail transport and generally of cars, operate a great deal of the time well below their peak efficiency, and a substantial proportion of the total energy consumption of transport is due to this. Undoubtedly, in the case of urban car transport a great deal of this could be avoided through the improvement of traffic flow, partly by better segregation of the various traffic streams (freight, buses, cars), and partly by more sophisticated electronic traffic control, and further research in the latter field is to be encouraged.

When all this is done, however, there still exists much scope for further saving of energy lost in the transmission system and in braking, and this not only in road but equally in rail transport. The Group commends the following directions for further R & D in this respect:

- more efficient and flexible automatic transmission systems for cars, probably via electronics rather than hydraulics;
- more efficient and compact regenerative braking systems, whether by flywheel or perhaps elastic hysteresis of suitable materials, or via energy storage batteries;
- more sophisticated control of the combined engine, transmission and regenerative braking system, e.g. by computer optimisation.

It was also noted that hybrid rail drive systems combining a diesel engine operating at constant speed with a sodium-sulphur storage battery providing peak power are possible and further developments in this direction are to be encouraged. As regards electric traction railways, the Group noted that the problems of using regenerative breaking in AC systems have yet to be solved satisfactorily. Light-weight storage batteries could also be used in combination with conventional electric traction systems.

However efficient the prime mover, the greater part of the input is wasted, and so, systems in which the waste-heat is small or recovered in a useful form and which are acceptable in transport vehicles need to be developed.

The energy consumption of a vehicle is directly related to its tare weight and the Group noted that the three-wheeler car with a two-stroke engine achieves typically 60 mpg (miles per US gallon) compared with the 10-12 mpg of the average US car (and, say 20-30 mpg in Europe). The development of a car combining light weight with adequate safety is urgently recommended.

Over and above all the foregoing measures, there is much scope for the raising of the thermal efficiency of vehicle prime movers, not only at their peak value but also over a wider range of operating conditions. Much effort has been already expended, but the energy crisis adds a new incentive to further activity in this direction. Most obviously, the replacement of the conventional IC (internal combustion with spark ignition) engine by the diesel engine with its 25-28% efficiency, can produce substantial economies most quickly. In London the substitution of diesel engines in taxi-cabs has produced a 50% fuel saving. Applied to the world energy picture, this figure implies a 6% net improvement. R & D is required to overcome the present disadvantages of the diesel engine in terms of noise, lower power density, higher capital cost at given power, lower acceleration and dirtier, smellier, though less noxious exhaust.

Further, the Group noted the substantial progress made in recent years in the development of a practical automatic Stirling engine, which in addition to an efficiency similar to that of the diesel, claims low-noise level, very low emission, flat efficiency/load curve, dispensation with lubricating oil and ability to operate on a wide range of low grade fuels. Its further development should be encouraged, and to this end R & D on the heater, preheater and high temperature materials of construction is required, as well as work on the engineering design so as to simplify its construction.

Thirdly, with recent developments of battery systems having more attractive power and energy densities, the prospect is improving for the all-electric car. Whilst its energy conversion efficiency may not be superior to the diesel and Stirling engines, the important advantages are: flexibility as to fuel sources in electricity generation, as to a possible link-up with centralized power distribution systems under or alongside the roads and from the point of view of automatic control, and higher system efficiency, because in a central power station the waste heat could be also utilized.

Lastly the development of hybrid systems is to be encouraged; e.g. a relatively low-powered diesel could operate at all times at peak efficiency, charging an electric storage cell. Dr. Goldman estimates that overall operating efficiencies as high as 35-38% are possible, compared with the present efficiency (10% in the U.S.A., probably 20% in Europe) of the straight IC engine driven car.

In railway transport where the low weight requirements are less stringent, such hybrid systems are already in the advanced stage.

II. Shaping of Materials

A. General Considerations

The Group felt strongly that in this field important energy economies can be obtained through better organization of production, standardization of products and avoidance of over-specification of material quality, and that these can be gained without technical R & D effort.

Inasmuch as the shaping processes absorbed an appreciable portion of the total energy consumption of national economies, shaped products should be made to last longer. Life can often be prolonged with negligible extra energy outlay by improving the quality of the material, e.g. by protection against corrosion and wear.

The primary material processes for conversion of e.g. metal ores into semi-finished materials which constitute the starting point for the shaping processes consume as much and not infrequently even much more energy than the latter. Further, shaping is mostly a multi-stage operation, much of it carried out at elevated temperatures, involving repeated intermediate reheating and final heat treatments. Heating consumes several times more energy than the shaping proper. Additional energy is required in ancillary treatments, e.g. pickling and coating. These facts lead to the following general conclusions about achieving energy economies:

- As far as practicable, replace shaping processes, having a low metal yield,—i.e. those processes whose end products contain only a small fraction of the metal used—(e.g. machining) by high yield processes, notably casting and plastic forming (e.g. extrusion, spinning). Use fabrication extensively as a means of producing complex shapes.
- Favour processes in which the final shape is achieved in the least number of intermediate stages, e.g. casting, extrusion, powder compacting.
- Favour shaping at lower temperature, even though the mechanical forces required are greater in this case. Where appropriate, electroforming should be developed further.
- Develop scrap recycling processes which by-pass the primary stage, e.g. direct compaction of turnings into reinforcing bar.

B. Specific Opportunities for Better Energy Utilization

Much energy is lost between the points of input into the machine and the point of application to the material which is being shaped. For example, in machining, a transmission or coupling efficiency of less than 50% is common. There is scope for considerable improvement of this by engineering developments of shaping machinery, and even more readily by good tribological practices of maintenance.

The utilization of shaping machinery is generally low, and energy is wasted by idling. The most obvious way of improving this state of affairs is by promoting continuous processes. Not all the technology is available, and even where it is applied there is scope for further development, e.g. in continuous casting of tubular and other slender shapes.

The potential of casting needs to be explored further with the view to achieving greater complexity of slender shapes in the more "difficult" metals, coupled with the right mechanical properties of the finished product.

Powder technology is considered to be probably the most promising of the shaping processes with reference to energy economy. It is thought however that existing research programmes are sufficient.

The conventional heating and heat treatment processes are known to be very inefficient. Processes generating heat *in situ* require further development, e.g. induction heating of conducting materials and perhaps microwave heating of non-conducting materials. The development efforts should concentrate on cheaper sources of energy for these processes (e.g. low *vs.* high frequency, chemical maser, induction coils operating in the superconducting state).

Where multistage (or even single step) operations are unavoidable, the possibility of recovery of the energy lost by cooling should be looked into (e.g. in the water atomization process of manufacture of powder).

In cutting and welding there is scope for energy economy by the use of more concentrated heat generation e.g. by electron beam and laser, but the cost is at present prohibitive, hence the incentive for R & D devoted towards cost reduction of these systems. Also in view of the low efficiency of electricity at the plug, non-electrical methods (e.g. chemical maser, thermite welding) and cold methods (gluing) should be developed.

III. Motion in Industry

Professor Murgatroyd estimates that in heavy and light engineering, where induction motors are the principal source of motion, these are essentially unsuited to the characteristics of most processes where there is a demand for low and variable speeds and frequent starting and stopping. Owing to this and the need to introduce extra transmission devices, the overall efficiency of utilization of the prime mover output over the working day averages approximately 25%.

R & D effort in this area seems therefore eminently worthwhile. One notes that the usual speed/force characteristics of the load are more readily matched by hydraulic rather than electrical power, and so, in addition to hydraulic transmission systems complete with hydraulic power drives, perhaps even centralized systems ought to be seriously looked into.

The Group notes that much of the current inefficiency is due to poor maintenance standards and shortcomings in the reliability of equipment, both of which should be remedied, even before embarking on R & D.