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The Future of Powertrains and Changes in Emissions Standards

David E. FOSTER

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Interview
インタビュー

The Future of Powertrains and Changes in Emissions Standards.

Professor David E. Foster
University of Wisconsin, Department of Engineering

Dr. David E. Foster is a professor of Mechanical Engineering at the University of Wisconsin-Madison where he is the Past Director of the Engine Research Center. Researchers at the Center study problems in combustion, fluids, sprays, heat transfer, lubrication, and materials related to engines.
He is a recipient of the Ralph R. Teetor Award, the Foster R McFarland Award and the Lyoyd L. With Distinguished Speaker Award of the Society of Automobil Enginerrs. He has served as a member of the National Research Council PNG Review Committee for the past tree years.

<Interviewer>
Neal Harvey, Senior Vice President, Horiba Instruments, Inc.
Cordinated by Masayuki Adachi (Horiba Ltd.),

1999年5月28日，ホリバグループの米国会社Horiba Instruments Inc社の副社長ニール・ハーヴェイは，ウインスコンシン大学のエンジンリサーチセンタの前所長デビッド・フォスター教授の研究室を訪れ「パワートレインの将来と排ガス規制の動向」についてお話を伺いました。インタビューは，内燃機関と化石燃料の将来性についてで始まり，燃料電池やハイブリッドカーについての見解を述べられ，さらに，国によって異なる排ガス規制へと活発な意見が交換されました。最後に，排ガス計測技術の向上に果敢に挑戦するホリバへの期待で締めくくられました。

On May 28, 1999 at the University of Wisconsin-Madison, Mr. Neal Harvey, Senior Vice President of Horiba Instruments, Inc. interviewed Professor David E. Foster, the Past Director of the Engine Research Center. Prof. Foster offers his view of the trends, opportunities, and challenges that will influence the development of powertrains in the next decade and beyond. The discussion begins with the future of the internal combustion engine and liquid hydrocarbon-based fuels. Prof. Foster shares his informed opinion about alternative power plants, including fuel-cells and hybrid engines. The participants discuss changes in emission standards and differences in vehicle emissions regulations in different countries. The interview concludes with a discussion of the technical challenges that face scientists and engineers who are working to improve emissions-measurement technologies.

N.H.: "Where do you see the development of automotive powertrains headed in the next ten or twenty years?"

D.F.: "In my opinion, ten to twenty years from now, the primary power plants for personal transportation are going to be internal combustion engines with some sort of petroleum-like fuel. I say that because the internal combustion engine is where it is for a good reason: it is responsive to highly transient operation and it has a high power density. The liquid hydrocarbon fuel has very high energy density, which makes it very convenient for on-board storage in transportation systems. The fuel is relatively safe to handle and there are significant challenges with any alternative that you think about."

"Also, the rate at which oil reserves are being found is relatively high. The oil industries have a usage-to-reserve ratio that is less than 100 percent. Over the past several years, they have found more reserves than they have taken out of the ground. Natural gas and coal are very plentiful and the technologies exist so that the price of oil, per-barrel, does not have to reach historically unprecedented levels before technologies for making a good liquid fuel from natural gas or coal become viable. So, barring some sort of political upheaval, for the next twenty years or so we will have an available a supply of inexpensive, high-energy-density liquid fuels, either directly from the ground or fabricated."

"These two facts, combined with the infrastructure that's in place, suggest that the internal combustion engine is going to be around for awhile."

N.H.: "What do you see as the most promising of the new technologies for the internal combustion engine?"

D.F.: "Direct-injection gasoline engines are undergoing rapid development and direct-injection diesels for passenger cars are commonplace in Europe. However, I think that the answer is largely in the political arena, because the development of the engines and different vehicle technologies is driven by their potential to meet emission and/or fuel economy regulations. For example, the LEV-2 standards suggested by the California Air Resources Board are very stringent. For a passenger car diesel engine to meet these standards will require very aggressive exhaust gas after-treatment as well as an advanced combustion system and modified fuel composition. Whether these technologies can be developed to be reliable and manufacturable on a large scale, in a time-frame consistent with phasing-in of those emission regulations is difficult to predict."

"Considering today's technology, the LEV 2 standards tend to favor the conventional spark-ignition engine-the one we know in the United States. In Europe, the more stringent regulations are being phased in more gradually, which promotes an evolution of the diesel exhaust after-treatment processes. I expect to see diesel-type power plants continuing to progress in Europe with an advent of more extensive exhaust gas after-treatment. An interesting aspect of exhaust gas after-treatment is that it places requirements on the fuel. This in essence mandates a paradigm

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＜パワートレインの展望と排ガス規制の動き＞

N.H.:「今後10年から20年の間，エンジンはどうなってゆくと思われますか？」

D.F.:「10年後, 20年後も, 人の輸送のための基本的なエンジンは内燃機関が主流を占めるでしょう。内燃機関は極めて連続的に機能し, エネルギー効率も高いからです。実は, 石油は採掘量よりもたくさん埋蔵されているようです。今後しばらくの間は, 内燃機関が健在だといえます。」

N.H.:「内燃機関について最も期待できる新技術としてはどのようなものがありますか？」

D.F.:「直噴式ガソリンエンジンや乗用車用の直噴式ディーゼルが有望です。エンジンや周辺技術の開発は排ガス規制の動きに強く影響を受けます。たとえば, カリフォルニア大気汚染対策局のLEV-2標準は非常に厳ししいものですが, 規制の厳しさに対

shift, we must now view the fuel, engine, and exhaust gas after-treatment as an entire system, as opposed to independent entities-because they all interact. The emission and fuel economy regulations will drive the new technologies that will emerge in internal combustion engines, which will probably be different in different parts of the world. That is, in the near term, the ‘winning’ technologies will probably be indirectly determined in the political arena.”

N.H.: “What do you think about the fuel cell?”

D.F.: “There has been very exciting progress in the fuel cell. The power densities available in the fuel cell have increased dramatically. The developments in terms of manufacturability and cost reduction are impressive. In my opinion, the real challenge of the fuel cell can be boiled down to ‘where do you get the hydrogen?’ In all cases some sort of feedstock will need to be processed to get the hydrogen. This processing can either be done on or off the vehicle. If it is done off the vehicle then one needs a hydrogen storage system onboard. Onboard hydrogen storage leads to a simpler powertrain but has the disadvantage that the amount of hydrogen that can be carried on the vehicle limits the driving range. I have heard estimates that with onboard hydrogen storage, the vehicle range would be similar to that of an electric car. If one tries to design an onboard reforming system the powertrain becomes very complicated, and expensive.”

Neal Harvey

Senior Vice President
Horiba Instruments Inc.

N.H.: “Will the overall thermal efficiency for a fuel cell system be competitive with the internal combustion engine?”

D.F.: “I think that if one looks at what is referred to as ‘wells-to-wheel-efficiency,’ that is the efficiency from the source of the energy to driving down the road, the fuel cell and a good internal combustion engine will be quite competitive. The fuel cell will probably have a higher on-road efficiency, however the losses that occur in the processing to get the hydrogen will be larger than the losses incurred in the processing of a typical internal combustion engine fuel. When one considers all of the losses, which is the correct thing to do, the efficiencies of the fuel cell and the engine are not so different. The fuel cell vehicle will probably have lower emissions, however. Whether this will be sufficient to offset their higher cost will be determined by whether engine emission reduction technologies can be developed to meet the ever-tightening standards.”

N.H.: “Would you view the hybrid engine as an interim approach to the fuel cell, which could be the ultimate solution, or will it be just be another alternative to fuel cells and internal combustion engines?”

D.F.: “The hybrid needs a major power source. It could be an internal combustion engine, or a fuel cell. The general philosophy of hybrid design is: ‘If you generate more power than you need, store it for later use.’ This sort of logic could be instrumental in a fuel-cell vehicle. For

応して , 技術は大きく発展しています。注目すべき点は , 従来は個々に検討されてきた , 燃料 , エンジン , 排ガス処理などの技術を , 今や相互に関係し合う一つの総合システムとして見直す必要が出てきていることです。ある意味では , 技術開発の選択権を規制が持っているとも言えるのではないでしょうか。」

N.H.: 「燃料電池についてはどう思われますか？」

D.F.: 「燃料電池はとても大きな発展を遂げていますが , 燃料電池自動車開発における真の挑戦は「どこから水素を持ってくるか」に尽きます．水素をうまく車に蓄えておくことができればずっと単純な構造になります。しかし , 電気自動車と同様に , 車に積み込める水素の量によって走行距離が制限されてしまいます。この課題を解決しようとすれば , 結局は , 複雑で高価なものになってしまいます。」

N.H.: 「燃料電池の総熱効率は内燃機関に見合いますか？」

D.F.: 「エネルギー発生から走行までの総合的な熱効率をとってみると , 燃料電池車

example, if one were to use onboard fuel processing to get the hydrogen for the fuel cell, one would probably employ some sort of hybrid powertrain configuration. The onboard processor might not operate well in transients, or may need additional time to start from cold conditions. Hybrid concepts could alleviate these challenges. For onboard hydrogen storage, the fuel cell vehicle is basically an electric car, so hybrid concepts may not be too useful. Finally, the meaning that many people often attach to the expression hybrid vehicle is one in which you've got some sort of reciprocating piston engine plus an electric motor. It is a more narrow definition than I am using here."

"The motivating logic for the hybrid is to operate the engine in the most advantageous condition, such as highest efficiency, for as much of the driving cycle as possible. If the engine is generating more power than is needed, you store the extra work, to be used later. If you fill up your storage you can even turn the power source off for a while. This is done in the Toyota Prius. Consequently, you use an engine which, when operating at its peak efficiency, produces approximately the average power needed by the vehicle. There will be operating conditions where you will need an excess of power, more than the engine can supply. When this occurs you draw on the stored energy plus the engine itself, to meet the power requirement. That is, you are now subjecting the car to driving conditions where the maximum power demanded is not always available to you. The maximum power capability of the vehicle depends on the state of the energy storage reservoir."

"For example, imagine that you want to tow a boat up to the mountains. A hybrid vehicle would not be a very good choice because you will be operating for a sustained period at a very heavy load. You will eventually run out of your storage. In other words, one needs to optimize the size of the engine along with the storage capacity and electric motor to some driving cycle. If the driving cycle includes extended periods of light load or idle, like traffic in Tokyo, then a hybrid vehicle can make a lot of sense. You can shut the engine off and sit there. When it's time to go, you use the electric motor. When you need to recharge the battery, the engine starts. It works well. If you live in an open space, for example the midwestern United States, where you drive on open roads for prolonged periods of time, the hybrid may not make so much sense."

"In my opinion, from an engineering standpoint, the hybrid question hinges on two issues: (1) the cost of fuel and (2) the nature of the driving cycle. If one does a comparison between the cost and performance of the best internal combustion engine system and the best hybrid system, the viability of the hybrid will depend heavily on the cost of the fuel. Can you justify the incremental cost of the hybrid because of the incremental gas mileage improvement or fuel savings? With the cost of fuel in the United States, I am quite skeptical that the incremental gas savings will justify the increased cost. The hybrid is going to be hard to justify from a purely economic standpoint."

"However, there are varying extents to which one can hybridize a vehicle. It may be possible to use the hybrid selectively to offload the engine from certain operating conditions where the emissions are particularly high. You could use it as a means of meeting emission regulations. It's very exciting, all the possibilities. But I still come back to the pragmatic standpoint of the

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は内燃エンジンに匹敵するものもあります。一方, 燃料電池は排ガスの面で大きなメリットがあります。この点が, 年々厳しくなる排ガス規制への対応を含め, コスト高をいかに払拭できるかの課題になります。」

N.H.: 「ハイブリッドエンジンは最終的な解決策となり得ますか？」

D.F.: 「ハイブリッド車の課題は燃費と走行サイクルに集約されます。つまり，走行中に必要以上のパワーが生み出された時に蓄えておき, 走行開始直後などパワーが必要になったときに引き出すシステムのことです。おそらく, 水素を予め積み込むタイプの燃料電池車ではハイブリッド化が基本になるでしょう。もちろん, エンジンサイズ，貯蔵能力，電気モータのバランスを, 走行サイクルに合わせて最適化する必要があります。東京のような渋滞した道路の場合には, ハイブリッドカーは非常に良い選択でしょうが, アメリカ中西部のような空いた道ではノーでしょう。排ガス規制対策上はハイブリッド化は有効かもしれませんが, しかし, 現実的には, 燃費と走行条件を考慮すると難しいでしょう。」

cost of gasoline and the driving cycle as to whether or not it can be justified.”

N.H.: “When it comes to regulatory requirements for measurements of gaseous emissions, I see that the focus on specific gaseous emissions differs from country to country. Why do we have such differences between the countries?”

D.F.: “Within each country, researchers have been assessing their specific problems. In the United States, in areas such as the Los Angeles basin, in metropolitan areas like Denver, and New York City, interpretation of the data has indicated that to reduce smog requires very stringent regulations on nitrogen oxide and unburned hydrocarbons emissions. Consequently, there is a tremendous push to try to minimize the NO_X and hydrocarbon emissions. In Europe, there has been a high penetration of diesel passenger cars into the market. In the United States, diesel passenger cars have essentially zero market penetration. The diesel engines are more efficient than typical gasoline engines but they usually emit higher levels of particulates and NO_X than gasoline spark ignition engines do. Different countries have different perspectives on the relative weighting of fuel economy, emissions and driving characteristics. As I have said previously, the regulations can be used to encourage the introduction of different technologies. Taking all of these factors into account, the different geography, the different driving patterns, vehicle performance preferences, and opinions of fuel economy and emissions, results in different regulatory emission levels for different compounds.”

N.H.: “Do you see any driving forces toward changes in what new components of emissions get regulated in the future here in the United States or in other countries around the world?”

D.F.: “I think there will be strong driving forces in this area. You see some of that already, for example unburned hydrocarbon emissions are now measured as non-methane organic gases, because methane does not participate in photochemical smog reactions to the extent that other hydrocarbons do. So we are seeing some of that discrimination already. Furthermore, I know that within the scientific laboratories of the automotive manufacturers they are assessing the photochemical activity of the individual hydrocarbon species coming out in the exhaust gas. So it seems logical that this will progress into regulation.”

“If one imagines that there will be regulation on greenhouse gasses, (which is to say fuel economy), then it would make sense to say that there would also be regulation on gasses that have high infrared cross-sections such as N_2O. That might come across as specifications in catalyst performance, for example.”

“As the community gets smarter about the details of trace species in the exhaust, the challenge will be for the regulators to craft comprehensible standards that still allow industry flexibility in product design toward meeting the goals.”

N.H.: 「排ガス測定の法規制は，国によって異なるのでしょうか？」

D.F.: 「燃費, 排ガス, 走行条件のどれを重視するかは, 国によって様々です。アメリカでは, ロサンゼルスなどの都市部でデータを解析した結果, 窒素酸化物と炭化水素が大気汚染の主因となっていると指摘され, これらの低減のために非常に努力されています。一方, ヨーロッパはアメリカと違い, ディーゼル乗用車が主流ですから, 粒子状物質(PM)やNO_xが問題になります。規制は新しい技術開発を推進します。地理的条件, 走行パターン, 自動車への要求性能, さらに燃費や排ガスに対する考え方が違えば, 規制対象物質も異なってきます。」

N.H.: 「今後，規制対象物質は変わって行くのでしょうか？」

D.F.: 「大きく変わって行くと思います。その動きは既に始まっています。たとえば, 現在, 未燃焼の炭化水素(HC)は, ノンメタンガスを計測してきました。これは, メタンが, 他のHCに比べさほど光化学スモッグに影響を与えていないためです。規制を

N.H.: "It could be tragic if, in our effort to reduce global warming, we reduce CO_2 yet we generate a much higher proportion of N_2O."
"Any final comment?"

D.F.: "A colleague, Professor John Heywood of MIT, made a comment that is absolutely consistent with my observation: right now, the transportation, power generation, and mobility field is as active as I have ever seen it. The challenges of trying to minimize these systems' impact on the environment have raised some very difficult technical hurdles. The issues involved transcend political, economic, and technical arenas. If a company can't meet the regulations, they can't sell their product. So, they're willing to investigate many different approaches to meeting the regulations. Five or ten years ago you would have laughed at some of the approaches being pursued today. Technology is now making things viable that, previously, would not have been. The demand for an efficient and clean transportation system is raising the hurdle very high. It is very exciting-the possibilities worthy of investigation are rapidly expanding. So companies like Horiba need to continue in their role of providing good and accurate measurement systems, and interfacing with people involved with the work so that, indeed, the society can move forward."

N.H.: "Thank you very much."

通じてアセスメントが進んでいくことは理にかなったことだと思います。温暖化防止の面からは, 亜酸化窒素(N_2O)のように赤外線吸収の強いガスを規制対象にするべきだと思います。排ガス成分に関し詳しい知識が得られるのに従い, 規制の策定側も, 目標達成に向けて柔軟な製品開発ができるような, 分かりやすい内容を指向するでしょう。」

N.H.: 「最後になにかありませんか？」

D.F.: 「私の同僚のヘイウッド教授の言葉ですが, 非常に共感できるので引用します。"現在，自動車エンジン業界は活発に活動している。一方，環境保全の面で大きな障害があり，政治，経済，技術の分野にまたがっている。これを乗り越えなければ製品は売ることもできないため, 10年前なら笑い飛ばされていたような試みもが研究されている。技術は不可能を可能にしてきた。" ホリバのような企業は，より高品質で正確な測定装置を積極的に提供する必要があります。そうした活動により，真の意味で，社会が前進できるものと信じています。」

N.H.: 「どうもありがとうございました。」

(抄訳　編集部)