Development and innovations regarding future tyres -- Challenges for the automotive industry

Ulf Sandberg
Swedish Road and Transport Research Institute (VTI), SE-58195 Linkoping, SWEDEN,
and Chalmers University of Technology, Dept. of Applied Acoustics, SE-41296 Gothenburg, SWEDEN

ABSTRACT

This paper describes some trends in tyre design and performance based on a tyre development by traditional means, as well as looking at some innovations which may provide breakthroughs that could have substantial effects on vehicle design. The author especially focus on the development driven by increasing demands on less environmental pollution, such as lower noise and lower rolling resistance.

It is concluded that tyres featuring low noise and low rolling resistance will be required in the near future and that the interest in and need for improved characteristics in this respect will receive much more attention and priority in the tyres of the next 10 years than for present market tyres.

There are indeed possibilities to reduce noise and rolling resistance further than today by traditional tyre design measures; in particular if the extreme high-speed demands (speeds in excess of 200 km/h) can be abandoned.

It is further concluded that there are several possibilities for a breakthrough in tyre design for low noise and low rolling resistance within the next 10 years or so, provided sufficient resources are spent on developing the concepts presented.

Key-words: tyre, innovation, noise, rolling resistance, tread, composite material, polyurethane

INTRODUCTION

Since its invention more than a century ago the pneumatic tyre has been developed to a highly sophisticated product with rather amazing performance. Something like four one square decimetres of tyre/road contact patches are, through the four tyres, able to provide a safe and comfortable road support for a 1500 kg car traveling at 200 km/h; of course subject to the driver behaving in a clever way. This development of the pneumatic tyre has occurred in a great number of rather small, consecutive and logical steps rather than in dramatic and epoch-making innovations.

This paper attempts to describe some trends in tyre design and performance based on a continued development in small steps, as well as looking at some innovations which may provide breakthroughs that could have substantial effects on vehicle design. The author especially focus on the development driven by increasing demands on less environmental pollution, such as lower noise and lower rolling resistance.

POSSIBLE FUTURE REQUIREMENTS ON VEHICLE AND TYRE NOISE

Within a few years, it is very likely that both the EC and the ECE have introduced a new measurement method for vehicle noise intended for type approval. Work with this purpose is presently at a near-final stage in both the ISO and the ECE/WP29/GRB and the EU Commission seems to be prepared to follow the ECE. New noise emission limits, including future steps to tighten these, are already suggested at ECE in Geneva.

The effects of these will mean that an increased attention will have to be devoted to the tyres. Originally, this was thought to be the case only for light vehicle tyres but recent test results seem to suggest that the same is likely to apply to heavy vehicle tyres.

At the same time, there is pressure on the EU Commission to tighten the tyre noise limits presently defined in Directive 2001/43/EC. A recent review of the limits and the possibility to lower them, made by FEHRL, suggested rather significant reductions in the limits within the next decade; actually starting in just a couple of years. A great number of non-industry organizations have expressed support for such actions.

Even retreaded tyres, so far being exempted from noise limits, are subject to new noise regulations; work on this is underway in the ECE.

Therefore, it is concluded that a dramatic increase in attention to the exterior noise emission of tyres will be needed within the coming decade. Of course, the tyre manufacturers will attempt to meet the new requirements by small modifications in the traditional tyre design, but it will be more and more interesting to start looking at rather different designs which may provide an "easier" and maybe more economical solution in the future. This author also thinks that in the coming years a greater part of the development resources will be spent on noise issues than in the past.

An example of this is the two currently running EU projects SILENCE and QUIET CITY; large integrated projects which both have substantial noise-reduction activities directed towards tyres.

Other examples are the increasingly more frequent occurrence of low-noise arguments in tyre advertisements and the use of "decibel" in some tyre brand names; see e.g. [Yokohama, 2005].

LOWER ROLLING RESISTANCE

The increasing concerns over the green-house effect will in the near future require more attention to rolling resistance than ever before; in fact from an already high attention to a very high attention.

The trend towards lower rolling resistance has been obvious for many years. Significant progress was reported in the recent Tyre Energy Efficiency Report in reducing rolling resistance, as measured for new passenger tyres, over the past 25 years. More tyre models today, when measured new, have rolling resistance coefficients below 0.009, and the most energy-efficient tyres have coefficients that are 20 to 30 percent lower than the most energy efficient radial models of 25 years ago [TRB 286, 2006].

Another trend is the increased popularity of run-flat tyres; mostly having stiffer sidewalls or some material added that can avoid running a flat tyre on the rim. The above-mentioned Tyre Energy Efficiency Report concluded that run-flat tyres weigh more than conventional radial tyres — which increases their material and production cost — and they tend to exhibit higher rolling resistance. This author thinks that this may turn the trend back to more traditional designs, or turn the interest over into designs which have run-flat capabilities **without** increased rolling resistance.

The increasing popularity and more frequent governmental support for hybrid or electric vehicles will also require lower rolling resistance since this directly affects the distance one can run in the electric mode.

Finally, it shall be mentioned that labeling of energy efficiency (in practice rolling resistance) of tyres is likely to happen in the near future. The intention is that consumers will use this information to their selection of replacement tyres; perhaps even vehicle manufacturers would use such information when deciding on OE tyres if this information will be available for the full range of tyre brands and dimensions and not only be determined by themselves for a few tyres. A conference organized by the IEA in November 2005 [IEA, 2005] indicated a rather universal support for the labeling of energy efficiency and also the Tyre Energy Efficiency Report suggested this.

INCREASING CONCERN FOR LOW NOISE AND ROLLING RESISTANCE NECESSARY

Both rolling resistance and noise emission are expressions of energy losses in the rolling of tyres. It is not surprising that these characteristics are at large positively correlated; although exceptions exist. Nevertheless, it is this author's conclusion that exterior noise and rolling resistance will drive the tyre development to a large extent in the coming years [Sandberg, 2003]. Probably, the present focus on high-speed and high-power performance, which both are in some conflict with low noise and rolling resistance (and thus air pollution), will at last have to give in to the latter performances.

Another present trend is the high priority put on the visual appearance of tyres, as a selling argument; in particular for "sporty" vehicles. The styling trend was heavily criticized recently as being in conflict with good technology by one of the foremost tyre experts in the world, Dr Joe Walter, in a column in Tire Technology International [Walter, 2006]. It is likely that this trend will be broken when it is in conflict with the increasing environmental demands.

Vehicle manufacturers will have to face the possible effects of this which may be uncomfortable to some.

OPTIONS AVAILABLE WITH TRADITIONAL TECHNOLOGY

Using traditional technology, the author suggests the following options as a few examples for reduction of noise:

Adapting winter tyres for all-year use: The principles used in construction of winter tyres may be partly adapted to summer tyres; in order that summer tyres may obtain some of the favourable noise characteristics of winter tyres; yet having handling and wet friction properties acceptable for summer use. This may include using smaller tread elements, more frequent siping and softer rubber compounds.

Some compromises like these mentioned above are already seen in the all-weather designs being so popular in the USA.

Can some winter tyres even be used the entire year? To answer this question, it is interesting that the author knows some tyre experts working for tyre companies who use "pure" winter tyres all the year. This is not to say that all or most winter tyres would be suitable also for summer use, but it suggests that at least some of them are so; probably with some sacrifices, for example wear.

Reducing the air/rubber ratio in the tread pattern: In the SILENCE project one of the possibilities being explored is the reduction of the air/rubber ratio in the tread pattern; for example by reducing the width of channels in the tread pattern. It has been found that a combination of softer rubber and lower air/rubber ratio may influence tyre/road noise emission on an ISO surface by about 6 dB(A). If, today's common ratio of 30 % is replaced with 20 % this would give a potential noise reduction of 3 dB(A). Work will continue; for example to see how a reduction from 30 to 20 % may be combined with acceptable hydroplaning characteristics (this may be difficult for high-performance cars).

Using softer rubber compounds: Typically, winter tyres may have a Shore hardness of 55-60. It has been well demonstrated that softer rubber compounds result in lower noise emission, other things being equal. If tyres did not have to be produced for such high speed categories as today, softer compounds may be used. Softer tyre rubber compounds are already used in Japan and in USA, but in Europe they are considered less acceptable due to the high maximum speeds on certain motorways. If, for example, the green-house effect will force also Europe to introduce maximum speed limits on all motorways, the situation might approach that in Japan and USA.

THE OPTIONS FOR LOWER ROLLING RESISTANCE

The examples above have potentially lower rolling resistance in common to the lower noise emission. However, the rubber compound is of extra importance here and additions such as silica mean progress to this performance parameter.

THE QUIET TYRE WITH NO MARKET

An example of a successful noise reduction design was presented in [Saemann et al, 2001]. Dr Saemann and his colleagues had produced, by means of traditional measures, a truck tyre that was equally quiet as a slick tyre. However, although the tyre had fully acceptable properties in other respects than noise, it was found that this tyre was not desired or needed by the vehicle industry, partly due to its visual appearance, partly due to that there was no need for any quieter tyre by the vehicle industry.

This author thinks that such neglect of quiet designs will be impossible in the future.

UNCONVENTIONAL TECHNOLOGY AND INNOVATIONS

The pneumatic tyre provides a rolling performance in most important respects that is amazing. Only a minor defect may demonstrate that this performance is not a matter of course but a result of a sensitive design. But this does not go without saying that the pneumatic tyre is the only useful device that could provide a safe, quiet and economic rolling for a vehicle. If a mere fraction of all the resources spent on tyre development so far would be spent on, for example, development of the composite wheel or the so-called TWEEL (see below), what can one achieve then?

An interesting editorial appeared in Tire Technology International recently. It was written by the former Director of Research at Dunlop Tyres in the UK, Dr A. R. Williams. He wrote [Williams, 2005-a]:

> "*So why is the industry almost afraid to move forward and challenge principles and practises that have been around far too long and not questioned? Who is stopping the questions even being asked? Are the answers such that the associated change is just too scary*?"

What is standing behind the corner? Are there some tyre innovations or unconventional designs that may offer a breakthrough or at least a large step towards lower noise emission and rolling resistance? The following describes a few examples of such attempts currently being explored.

THE COMPOSITE WHEEL AND THE TWEEL

Non-pneumatic tyres are not even subject of the tyre noise Directive 2001/43/EC; they are in this respect non-existing both presently and in the foreseeable future. Nevertheless, in the future it may happen that non-pneumatic tyres might replace pneumatic ones so it is interesting to see what possibilities there may be at the horizon.

Ongoing work led by the Swedish National Road and Transport Research Institute (VTI); in cooperation between a number of organizations and companies, attempts to study the feasibility of developing the composite wheel concept into a useful component [Sandberg et al, 2003]. The partners include for example Chalmers and VTI in Sweden, the Technical University of Gdansk (TUG) in Poland, Volvo Cars, Nokian Tyres, Fighter AB (a tyre retread company) and the inventor Mr Hansson. It has already been demonstrated that the composite wheel has a very large noise-reducing potential if properly designed (below all known pneumatic tyre designs), and recent results have indicated also superior rolling resistance performance. Its wet friction and hydroplaning properties should also be superior; however, it is unknown if it can be made durable enough, what handling properties one can achieve and how competitive production costs may be. Refer to Fig. 1 for an illustration.

Fig. 1. Early version of a composite wheel (not a good design re. noise). Note the ventilation holes in the tread. New version is underway in which the spokes are much better designed to reduce stiffness variations around the circumference and with better distributed ventilation holes.

The noise-reducing potential for a composite wheel has been demonstrated earlier to be around 10 dB(A); i.e. better than that of a patternless tyre on a smooth surface, and much better than any type of pneumatic tyre on a rough surface. Thus, it has the potential of a technical breakthrough, if properly developed; see further chapter 25 in [Sandberg & Ejsmont, 2002]. Measurements in 2006 have shown rolling resistance values some 20 % below those of the best known market tyres.

In January 2005, the Michelin concept wheel; the TWEEL, was presented. It has been developed at the Michelin research center in Greenville in the USA and has in 2005 received a number of innovation awards. An article in Tire Technology International describes this wheel which has a significant resemblance to the one in the VTI project [Williams, 2005-b]. There is a video film made by Michelin which shows an Audi A4 car driving around a curvy test track at relatively high speed on a set of TWEELs. However, it has been indicated in an interview with a Michelin official that there are some problems with vibrations from the spokes, just as has been experienced in the design in Fig. 2. Nevertheless, when developed further by Michelin in USA, it is possible that this concept may provide a technical breakthrough in terms of exterior noise emission and perhaps also rolling resistance.

Fig. 2. The TWEEL as it was presented the first time at the motor show in Detroit in January 2005. Photo kindly supplied by Dr Lin Kung, Kumho Tires, USA.

Michelin in Europe has its own concept; namely the Michelin Airless tyre, which was reported in a press release 2005-01-12 as: "Michelin Airless enables vehicles to run safely and comfortably because its elastic characteristics are controlled longitudinally, transversally and vertically. A car doesn't have to stop even if one or more of the radial bands break or are damaged. The Michelin Airless is being tested on passenger cars and motorcycles, but could be fitted to other vehicles as well". VTI tested a similar design in 1991, giving a noise reduction of around 6 dB(A) in relation to an "average" pneumatic tyre, and it worked well, except that the "spokes" created severe noise when they got in contact with each others over a certain speed (see Table 25.1 in the Tyre/Road Noise Reference Book). Therefore, the Airless tyre should have a good potential for noise reduction, if the problem of contacting spokes can be solved; which of course Michelin would be able to do. The Michelin Airless tyre picture cannot be shown here due to copyright reasons, but the VTI version from 1991 gives an idea of how it looks like, see Fig. 3.

THE POROUS TREAD TYRE

The project led by VTI on tyre innovations also looks at the possibility to replace the conventional patterned tyre tread with a porous tread. Speculations and some earlier testing suggest that such a porous tread tyre may have excellent wet friction and rolling resistance properties, but may sacrifice wear. Would a greater wear (if any) be acceptable? Would side force characteristics be acceptable? Further, a crucial point is if the porous tread can be sufficiently firmly connected to the carcass.

Fig. 3. Composite wheel, invented by Mr H. E. Hansson, tested by VTI in 1991, see Table 25.1 in [Sandberg & Ejsmont, 2002]. The Michelin Airless tyre somewhat resembles this design.

The tread produced so far is made up of rubber granules bound with polyurethane to create a porous structure with interconnecting air voids. The aim of the first phase of the project was to determine the potential noise reduction and rolling resistance of a porous tread tire. Fig. 4 shows the first prototypes of the porous tread tyre made in 2004.

Fig. 4. Two porous tread tyre prototypes together with the regular tyres used as carcasses for the porous tread (after buffing-off the existing tread).

Testing so far of the porous tread tyre has indicated very interesting results [Sandberg et al, 2005]. The results indicated that the noise emission was exceptionally low on road surfaces with a texture typical of Swedish highways. In comparison to the two commercial car tyres chosen as references, the noise reduction was about 7 dB(A) for both the narrow and wide tyres which is far below any other tyre measured. On very smooth surfaces, noise reduction was lower due to low-frequency noise being present as a result of the inhomogeneities in the handmade tread. Rolling resistance was about 10 % lower than that of a Michelin Energy 3A tyre which is the best of the conventional tyres measured by TUG so far. Wet friction was poorer than on the high-performance reference tyres; but can no doubt be improved substantially if high-quality rubber compounds are used instead of the low-quality recycled rubber used in the first prototypes.

Provided the friction, handling and wear properties of the porous tread tyre can be managed acceptably, this tyre may offer a technical breakthrough both for noise and rolling resistance. At first, handling properties due to the softness of the tread may not be sufficient for high-performance cars, but it is hoped that they may be acceptable for "normal" or for "city" cars. At least for wet friction, there is also a good potential, since the air volume in the tread is comparable to that of a summer tyre (in fact, approximately 30 % air voids by volume was measured) and all porous channels are very close to each other; shortening the escape time for water from a certain point in the tyre/road interface. Although friction on icy surfaces may be good, it is speculated that traction in snow may create some problems; thus the porous tread may not be ideal for all winter conditions.

THE SOLID POLYURETHANE TYRE

Some 20 years ago, tyres filled with solid polyurethane were tested for noise reduction. VTI and TUG still have such a tyre, sometimes used for testing purposes. This filled tyre produced about 3 dB(A) lower noise than its air-inflated counterpart (both were pattern-less). It is very interesting to note that polyurethane-filled tyres are no longer considered to be unrealistic. The US-based Amerityre Corporation (manufacturer of moulded-/filled bicycle and industrial truck tyres) is currently developing this concept for automobile use. For a few years, also Goodyear in USA was involved in this development.

The latest progress reported (April 2005) is that a tyre filled with polyurethane elastomer has been approved by NHTSA according to the Federal Motor Vehicle Safety Standard FMVSS 129 for use as a temporary/spare tyre [Amerityre, 2005]. FMVSS 129 is the applicable U.S. safety standard for new, non-pneumatic tyres that must be met before the tyres can be offered commercially. The appearance of this tyre is shown in Fig. 5. Note that such a tyre will never run flat; it is the "ultimate" run-flat technology.

Presently it seems that this type of tyre is useful only as a spare tyre and lacks the performance needed for normal use. However, if the industry would be willing to work on this, and pressure for improved noise, reduced vehicle size, and lower rolling resistance may play a role here, this author believes that the concept might have a certain potential for a breakthrough.

Fig. 5. Two polyurethane-filled spare tyres, approved by NHTSA, offered by Amerityre Corporation. The larger tyre is for a small-size SUV, rated for 2000 lbs, the smaller is for a regular car, rated for 1500 lbs. Photo used with permission, kindly supplied by Mr E Taylor, Amerityre Corporation.

CONCLUSIONS

It is concluded that tyres featuring low noise and low rolling resistance will be required in the near future and that the interest in and need for improved characteristics in this respect will receive much more attention and priority in the tyres of the next 10 years than for present market tyres.

If the climate changes will force a sudden and dramatic change in transportation and vehicle emissions policies, which is not an unlikely scenario, the tyre and vehicle manufacturer who fails to consider unconventional solutions may suddenly find itself in an inferior position to the one who can see and actually explore the possibilities of new technologies.

There are possibilities to reduce noise and rolling resistance further than today by traditional tyre design measures; in particular if the extreme high-speed demands (speeds in excess of 200 km/h) can be abandoned.

It is further concluded that there are several possibilities for a breakthrough in tyre design for low noise and low rolling resistance within the next 10 years or so, provided sufficient resources are spent on developing the concepts presented above.

FINAL REMARK

At the Tire Technology Expo 2007, 13-15 March 2007 in Cologne, Germany, there are plans for a special session on tyre innovations for lower noise and rolling resistance.

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