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Random load fatigue in tractor transmissions

Looking back, „random load fatigue“ in drive lines began in 1924 with A. Palmgren. Important advances came later from agricultural engineering – for tractor transmission after World War II. The position now achieved is partly thanks to the directional work of Prof. Dr.-Ing. E.h. H.-J. Matthies.

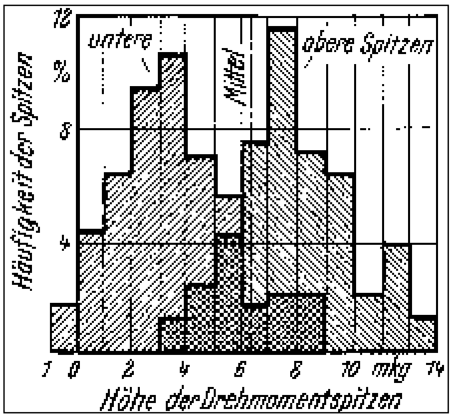

Fig. 1: Cumulative load spectrum (binder)1932 [2], original diagram, simplified

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As far as the author knows, first reference to „load spectra“ in worldwide literature was published (*fig. 1*) in 1932 by the agricultural engineers W. Kloth and Th. Stroppel [2] whereby they first used the term „spectra“ in 1936 [3]. Already recommended in [3] was a comparison of collective stress with Wöhler lines. Influences of the load cycle number on the dimensioning of tractor transmission gear wheels could be found as early as 1931 from L. Jacobi [4].

Cumulative load for tractor transmissions: First impulses from Brunswick

In 1953 A. Gerlach under H. Meyer („Schlepper- Meyer“) began fitting tractors with recording equipment (telemetry) in the Federal Agricultural Research Institute (FAL) and presented the first transmission load spectra [5, 6]. In 1956 H. Straub [7] found that with hard coupling the torque at the transmission entrance could also exceed the clutch slipping moment even with tractors (see earlier publications on road vehicles from H. Glaubitz.).

Gerlach's work was continued at FAL by H.H. Coenenberg in contact with the Institute for Agricultural Machinery at TH Brunswick under the then directorship of Prof. Dr.-Ing. H.J. Matthies. Coenenberg presented for the first time comprehensive findings on the dynamic torque behaviour of tractor transmissions [8]. In order to promote the use of load spectra, M. Kahrs (under Matthies) published an overview in 1963 [9]. The importance, as recognised by Matthies, of an improved layout of tractor transmissions lead to a popular special exercise course „Construction and calculation of tractor transmissions“ at the institute (Matthies/ Kahrs). The author was confronted with these sort of questions during his work with KHD 1965/66 whereby at that time a serious random load fatigue problem with gear wheels saw discussions over the amount of impact factor to be applied diverging strongly. As assistant to Matthies he subsequently began to collect layout guidelines through checking large numbers of tractor transmissions – the good relationship of Matthies to tractor companies was very helpful in this work. Core of the results featured the so-called „Sternhimmel“ diagrams in which layout limitations for tooth roots and flanks depending on the total cycle number were able to be calculated. On this, H. Regenbogen later published under Matthies first qualitative indications from the aspect of random load fatigue [10]. At around the same time, load measurements were conducted on a 70 kW tractor under H. Kühlborn at FAL [11] and were later continued by R.H. Biller.

Tractor industry discovers random load fatigue

After promotion by Prof. Matthies the author changed in 1973 to the management of primary development for tractors at Klöckner-Humboldt-Deutz AG (KHD) in Cologne. There, load spectra measurements on tractors had been conduced for several years under B. Breuer and U. Lüpfert [12] which had been initiated by KHD director O. May. Good layout fundamentals already existed for different tractor components [12] – although there was still insecurity as far as transmission was concerned. In comparison with the above-described work from Brunswick, the load spectra tended to come out too sharp. With this in mind, the author produced a total balance [13] in which the then available literature on random load fatigue of tractor transmissions and similar components were evaluated. Following this, details were discussed with authors, experiences from the above-mentioned checking flowed in, and consideration was taken from KHD results. In overall agreement with the earlier work from J. Deere [14] it was recognised that load spectra for gearwheel dimensioning should be based on numbering method „spot sampling with synchronised rpm“ (or „time proportion“ at constant rpm) [12, 15, 16]. The standardisation for the transmission entrance collective was carried out in [8] with the engine rated moment. For the load spectra on the drive wheel side, the author proposed tractor net weight, or alternatively, mid-value of net weight and maximum registered gross weight. The work further comprised driving speed spectra required for the estimation of the changing period of individual gears or driving range.

The use of these and further internal fundamentals on a newly developed Deutz tractor transmission [17] led, in relationship with the skill of the transmission builder W. Zenker to „TW90“ (later „TW900“) with cost efficiency and simultaneously higher reliability.

The total load spectra given in 1976 [13] are still useful nowadays as first stage. In 1982 R.H. Biller confirmed [] approximately the total spectra proposed by the author for the transmission entrance when one considered the different overlapping possibilities. The drive wheel side total load spectra proposed by him lay substantially under that of [13] and was shown in industrial application as, in fact, too low – H.-H. Meiners was a student of Matthies in [19] when he first calculated the oscillation damping effect for tractor transmissions of hydraulic clutches. Later, with [20] he produced a summary for the application of tractor transmission load spectra at KHD. In 1983 R.H. Biller published the pto load spectra of a 70 kW tractor for cultivation application [21].

Random load fatigue has established in drivelines

Many specialists did not for a long time trust the accuracy of linear cumulative fatigue damage hypotheses for transmissions. Since 1974, however, (provable 1975 [22]) the author held the view, however, the empirical and broadly supported theory that with cyclically-stressed machinery elements (because of the nearness to the demands of the Wöhler trial) not the cumulative fatigue damage but instead the calculation of „integrated component Wöhler lines“ represented the critical link in the layout chain – and one should use this in the planning of a first laboratory trial for a new construction [17]. In 1976 he proposed a general optimising concept based on the „Palmgren-Miner-Hainach“ [21] for the dimensioning of gear wheels according to load spectra [24, 25] (Model for the layered Wöhler lines). In the meantime, in FVA projects (under Prof. B.R. Höhn, TU Munich) it was accurately confirmed that the linear cumulative fatigue damage calculations for application hardened individual gear wheels was applicable: for the groove load fatigue in [26], for the tooth root load fatigue in [27]. Further work under B.R. Höhn showed that the load succession in the case of the groove random load fatigue did not have a negative effect [28]. At the author's Chair, B.Vahlensieck calculated first load spectra for tractor stepless transmissions, in particular performance regulating ones. [28]. With this, the calculation and testing of new automatic transmissions for tractors was supported. Further, in [28] a new dimensioning model for the (performance-critical) couplings of pulley converters [27] (see also Audi „multitronic“) over guided Rainflow coupling power spectra. H. Mariutti investigated at the same Chair cumulative stresses on a tractor with drive belt (with Rainflow numbers, among other methods) [30].

Summary

Methods of random load fatigue apply in mechanical engineering as economic and future-oriented. This report thus sketches advances for the layout of tractor transmissions in the last decades. Brunswick supplied important impulses in this – at the beginning rather from FAL scientists, later more from the „Matthies School“. This work led not only to improved calculations and trials of tractor transmissions but also fertilised other areas in drive technology.

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