Projections of Limiting States for Load-Bearing Structures of Reflector Made of Polymer Composites

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INTRODUCTION

By universal practice specific reflectors reliability affairs refer to evaluation precision of reflecting surface shape that is deformed under the influence of working loading. This concerns reflectors that are both stand-alone technical objects [1, 2] and a part of antenna arrays [3]. Commonly in the capacity of failure criterion one use mean square deviation of reflecting surface. It can be considered as both point estimate [1] and time variable [2].

Nonspecific reflectors reliability affairs come down to analysis of admissibility and conditions of limiting states occurrence that traditionally relate to domain of study of deformable solid mechanics, fracture mechanics and structural mechanics of composites. These reliability affairs are concretizes for technical objects taking into account structural materials properties, working loads characteristics, engineering and standard specifications for functional features.

Analysis of reflectors stress and strain states brings about the following list of limiting states that refers to load-bearing structures made of polymer composites:

- limiting states that appear as a sporadic state variables going over safe limit under condition of gravity and wind loads (buckling collapse of skeleton beams, breakdown of skeleton beams, breakdown of skeleton load-bearing fasteners);
- limiting states that appear as a sporadic state variables going over safe limit under condition of dynamic structural loading by means of sinusoidal vibrations and acoustic noise;
- limiting states that appear as of long-term structural material degradation.

LIMITING STATES CRITERIA

Reflector is supposed to be a system $S=\{K,M,J\}$ that consists of three type elements: skeleton beams K, reflecting segments M and coupling members (fittings f, rivets r, bolted connections b and glue junction g) $J=\{f,r,b,g\}$. The system is exposed by complex working loading $L=\{G,W,T,V,N\}$ by gravity G, wind W, thermal T loads, sinusoidal vibrations V and acoustic noise N. The proportion of internal force factors caused by complex working loading allows to define predominant cause-effect relations between limiting states and specified working loads.

Depending on beam elements placing in skeleton structure they can be subjected to tensile or compressive force F. For the compressed skeleton beams the first limiting state appears as a Euler buckling collapse. This limiting state criterion is exceeding of maximum compressive force over critical load F_c^K

$$F_{\max}^K(G,W,T) \geq F_c^K \mid F_{\max}^K < 0.$$

The second limiting state appears as one of specific failure mechanism for fiber composite under compression along the reinforcement direction (shear, interfacial failure, splitting, kinking) [4]. In general form the limiting state criterion is

$$\sigma_{\max}^{K}\left(G,W,T\right)\geq\sigma_{c}^{K}\mid F_{\max}^{K}<0.$$

where $\sigma_{\max}^{K}$, σ_{c}^{K} – are respectively maximum and critical values of compressive stress for each failure mechanism.

The limiting state criterion for tensioned beams is exceeding of maximum tensile force $F_{\max}^{K}$ over breaking force F^{K*} obtained by experiment:

$$F_{\max}^{K}\left(G,W,T\right)\geq F^{K*}\mid F_{\max}^{K}>0.$$

The relevance of limiting states analysis for skeleton load-bearing fasteners is confirmed by known cases of fracture of reflector structure bolted joints [5]. Joint assembly for skeleton beam elements is realized with using rivet and bolted connections, glue junctions of fittings and beams (*Fig. 1*). Limiting state of the junctions exposed to shear strain is exceeding of tangential stresses over similar critical ones:

$$\begin{aligned}\tau_{\max}^{r}\left(G,W,T\right)&\geq\tau_{c}^{r},\\ \tau_{\max}^{b}\left(G,W,T\right)&\geq\tau_{c}^{b},\\ \tau_{\max}^{g}\left(G,W,T\right)&\geq\tau_{c}^{g},\end{aligned}$$

where $\tau_{\max}^{r}$, $\tau_{\max}^{b}$, $\tau_{\max}^{g}$, τ_{c}^{r}, τ_{c}^{b}, τ_{c}^{g} – maximum tangential and critical stresses (failure shear stress) in rivets (*r*), bolted joints (*b*) and glue junction (*g*).

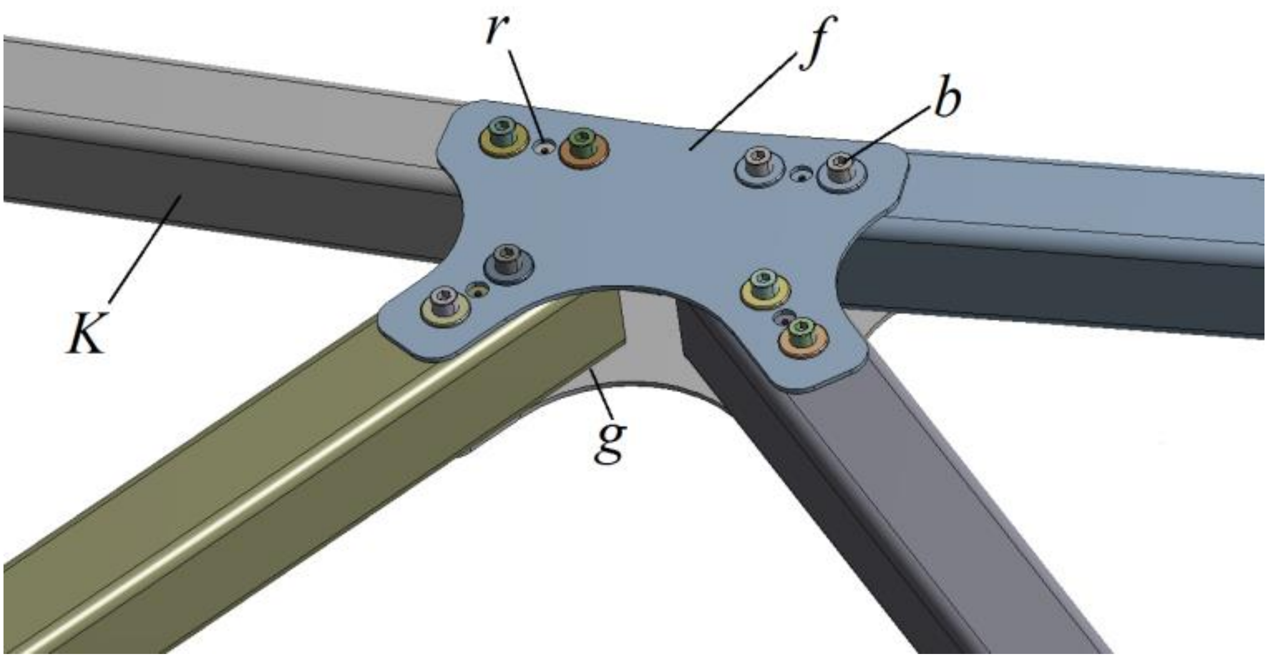

FIGURE 1. Typical joint assembly for skeleton beam elements: *K* – beam element, *f* – fitting; *b* – bolted connection, *r* – rivet, *g* – glue junction of fitting and beam

Limiting states of fittings appears as both fracture of fitting tensed in its plane and local fracture of fitting in and around bolted joint:

$$\sigma^f_{\max}(G,W,T) > \sigma^f_t \mid \sigma^f_{\max} > 0, \quad \sigma^f_{\max}(G,W,T) > \sigma^f_c \mid \sigma^f_{\max} < 0,$$

where $\sigma^f_{\max}$ – maximum fitting stress, σ^f_t, σ^f_c – ultimate strength of fitting material at tension and compression.

Analysis of the limiting states of reflector subjected to sinusoidal vibrations is fulfilled taking into account specified acceleration amplitude a for scheduled frequency range q (for designed reflector a = 40 m/s^2, q = [0…80] Hz). It is assumed that wind loads are active working loads generating sinusoidal vibration. When analyzing acoustic noise influence on structure one must take into account sound pressure level A_{db} for scheduled frequency range (for designed reflector A_{db} = 100 dB, q = [50…10000] Hz). To study conduct of structure under considered dynamic influence there is applied the harmonic analysis technology to compute reacting (Harmonic Response) of structural model to harmonic loads. Harmonic analysis results in computed amplitude-frequency characteristics indicating response of model parameters on external action frequency.

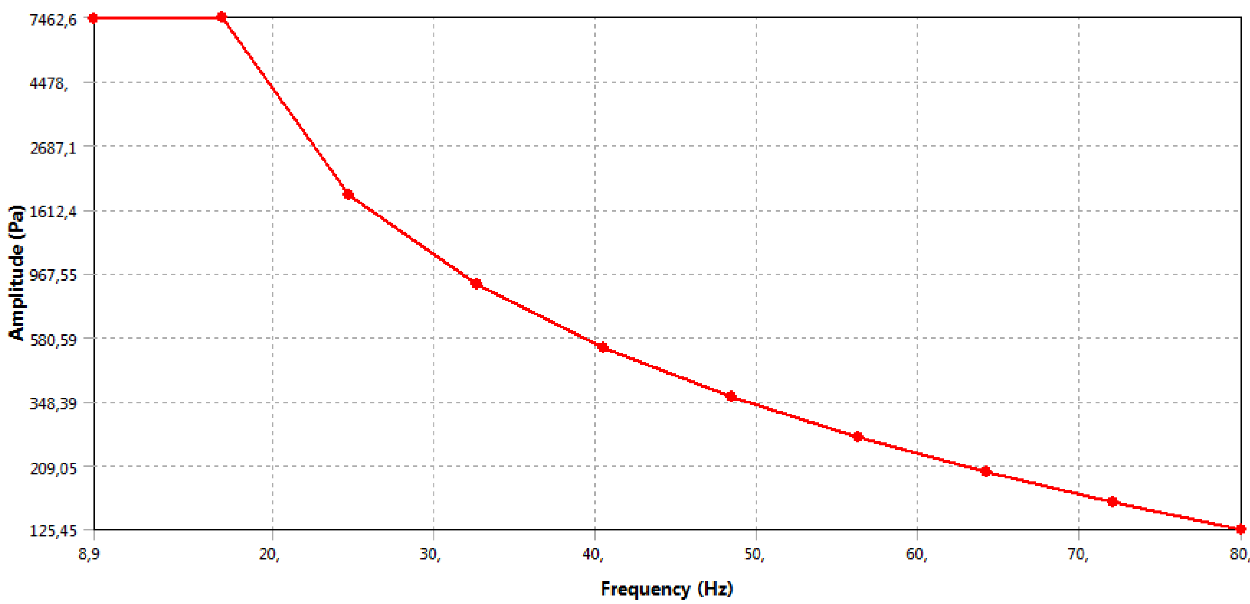

FIGURE 2. Typical amplitude-frequency characteristic of normal stress for load-bearing reflector structure under sinusoidal vibrations

Skeleton beams are the most stressed reflector elements under dynamic loading. In this connection it should be analyzed limiting states described by equations

$$\sigma_{\max}^{K}(V) > \sigma_{t}^{K}, \quad \sigma_{\max}^{K}(N) > \sigma_{t}^{K},$$

where $\sigma_{\max}^{K}(V)$, $\sigma_{\max}^{K}(N)$ – maximum axial stresses in skeleton beams under condition of dynamic structural loading by means of sinusoidal vibrations and acoustic noise.

In general the limiting states caused by long-term degradation of structural material may arise in any reflector structural elements. However comparative analysis of structural elements stressed states leads to the following conclusion. Limiting states caused by direct action of gravity, wind, thermal loads under static and dynamic loading are more probable for skeleton beam elements and fasteners. Reflective segments are less stressed. That is why the segments should be studied with relation to long-term degradation of structural material. In this case limiting state appears as exceeding of predictive estimate of the service life t_l over specified one t_n:

$$t_l(G, W, T) > t_n.$$

Service life of polymer composite structures by long-term strength criterion at a first approximation can be defined with fundamental dependence that characterize thermofluctuation fracture (Zhurkov formula) [6]

$$t_l = t_0 \exp(U_0 - v\sigma)/RT,$$

where t_0 – period of atom oscillation; U_0 – activation energy; ν – structural-sensitive coefficient; σ – stress level; R – gas constant; T – temperature

NUMERICAL RESULTS AND CONCLUSION

In practice considered limiting states criteria are defined on the base of numerical estimates of structure stress and strain states. The criteria are practically used for design study reflector antennas for terrestrial satellite communication systems working in conditions of Q/K_a frequency band. The reflector diameter is in the range 9 to 12 m and the ratio of the focal length to the diameter in the range 0,3 to 0,5. Obtained quantitative assessments confirmed their adequacy. These assessments allowed to substantiate decisions for structural optimization relating to reflector skeleton spatial structure and its beam elements cross sections. The used limiting states criteria are in the base of necessary and sufficient design analysis for ensuring required reflector specifications.

ACKNOWLEDGMENTS

This work was done during the complex project and was financially supported by the Russian Federation Government (Ministry of Education and Science of the Russian Federation). Contract № 02.G25.31.0147.

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