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A statistical assessment of brilliance and fire for the round brilliant cut diamond

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Abstract. The 58-facet round brilliant cut diamond is considered as a random scatterer of incident light. The diamond, of an axisymmetric design, is considered to be spinning and surrounded by a hypothetical sphere. The optical properties brilliance, sparkliness and fire are represented by statistical properties of the intensity distribution on the sphere. Using a computer model of the system, the effects on the three optical properties of changing the length of the pavilion halves and the table spread were investigated. The results confirmed that the traditional ' ideal ' cuts are satisfactory, showing the trade-off between sparkliness and fire that results with these ideal cuts. A new style is proposed with a deeper pavilion angle (53°), and this is shown to be superior to the traditional styles using the statistical measures.

1. Historical survey

Diamond has been valued as a talisman since ancient times, but only since the 17th century, and the styles associated with Cardinal Mazarin and Peruzzi, has cutting to produce a pleasing optical effect become popular. A stage in the development of the point cut into what now is called the round brilliant cut diamond, by trial-and-error methods aided by serendipity, was the ' old mine cut ' style (see figure 1), popular at the turn of this century. This style, with its high crown, steep pavilion and recognizable arrangement of facets, exhibits the three prized effects in a gemstone—brilliance, a measure of the light that, entering the crown of the stone, is scattered out of the crown facets, sparkliness, the amount by which this light sparkles, and fire, the chromatic variation of the sparkles. These visual effects are still quantified by reference to experienced judgement, there being no engine available to measure all three parameters.

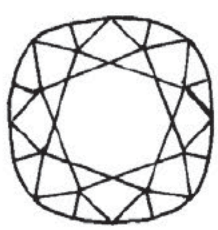

Figure 1. The old mine cut style (after Tolkowsky [1]).

With the fashion for mathematical determinaism in Victorian science, which carried over into the 20th century, it was inevitable that a mathematical description of the optical effects in a polished diamond should be sought. It was in 1919, when the technical optics section at Imperial College was ' one and just begun ', that Tolkowsky published a book, *Diamond Design* [1], while a member of the City and Guilds College (now the engineering school of Imperial College). This theoretical monograph was the first attempt to list the causes of the optical effects in gem diamond and set some simple criteria for their measurement.

Taking as his starting point a simple triangular cross-section, he used geometric and optical arguments to justify the necessity for, number of and arrangement of the facets on the centrosymmetric round brilliant cut diamond that was the old mine cut, and hence to confirm this as the ideal style for cutting a gem diamond by defining a criterion for maximum brilliance. This stated that the optical goodness of a stone is the product of the angular dispersion for a red and blue ray and the transmitted intensity for a green ray at the same angle of incidence. However, in the derivation of the functional form of this product, [1, p. 72] he appears to have confused Lambert's law with Fresnel's equations, and hence fortuitously deduces the ideal pavilion angle to be $40\frac{3}{4}°$. If the brilliance criterion is calculated using the exact formulae, but otherwise following the analysis of Tolkowsky, an ideal pavilion angle of about $39\frac{1}{4}°$ is found.

It is to be noted that Tolkowsky's ideal proportions (see figure 2) are accepted by the Gemmological Association of America as the best of the 'ideal' proportions proposed up to the present time.

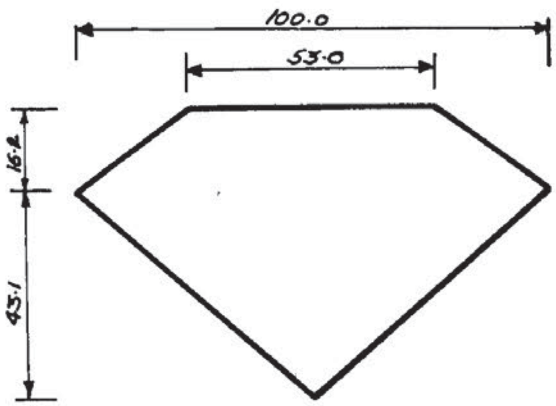

Figure 2. The ' ideal ' proportions proposed by Tolkowsky [1].

In 1926, Johnsen [2] used similar geometric methods to obtain another ideal set of proportions. These had a pavilion angle of about 39°, similar to the more exact analysis of Tolkowsky. In the same year, Rösch [3] published a set of ideal proportions and also developed a technique for producing, for a gem diamond, a reflection spot picture, the light analogue of the X-ray back-scattered Lauegram. These spot diagrams can be used to aid identification and to assess the optical goodness of the gem.

One prevalent argument at the time was that these optically ' ideal ' cuts were less economic than the mine cut since more material was removed, resulting in a lower yield from the rough. Because extra material had to be removed, and a higher accuracy and standard of workmanship were demanded, the stones took longer to manufacture and so the new styles were slow to be adopted. The final value of a stone depends on the ' four-Cs '—cut, colour, clarity (the freedom from both internal imperfections and artefactual blemishes) and carat weight (1 carat = 200 mg). By appraising many stones, Eppler [4] produced in the 1930s a set of practical cuts which helped to combat the resistance to the new styles of cutting.

In a paper which appeared in 1968, Eulitz [5] adopted a geometrical approach similar to that of Tolkowsky and Johnsen. Elbe [6, 7] has also produced some designs for a new type of round brilliant, as well as a diamond grading engine based on the method of Rösch. Most recently, Stern [8] has developed a computer programme that uses finite ray-tracing methods, and has confirmed that the traditional ideal cuts are satisfactory. He fails, however, to discuss any quantitative measures of optical goodness, proposing only a loose criterion for optical quality that is a restatement of a well-known preference; this will be given in the next section.

2. Factors affecting optical goodness

The non-expert normally observes a diamond set into jewellery with the pavilion obscured by the setting in diffuse illumination, with the unaided eye, and at a distance of about 50 cm (a relaxed arm's length). The observer moves both his head and the stone, and the overall brightness, rate of sparkle and chromatic variations in the sparkles are translated into degrees of optical attractiveness. It would appear that, when he judges optical attractiveness, the observer has in mind certain general principles and some specific likes and dislikes. In particular the illumination over the stone should be reasonably uniform, and there are two styles which offend this rule in the round brilliant cut. One is a stone with a deep pavilion (pavilion angle $\simeq 45°$), which gives the impression of a dark table, which is not surprising since the table–pavilion combination is like a corner–cube retro-reflector with the observer's head forming a dark central obstruction. The other is a stone with a shallow pavilion angle (of 37° or less) where the girdle, which often has a *brutted* or frosted appearance, is visible through the table as a white ring. In general terms, the greater the number and the smaller the average size of the sparkles, the more evenly will they be distributed. If this situation were to be modelled in every detail by a computer programme, it has been estimated that three hour's computing time would be required to perform the ray tracing alone, before any analysis of the data would be possible. A refinement of the Rösch's method [3] was therefore adopted.

3. The diamond grading model

A diamond is sourrounded by a hypothetical sphere centred on the table; rays in several azimuthal and meridional orientations, a form of pseudo-diffuse illumination, are then traced through the diamond, noting their Fresnel components at each partial transmission or total internal reflection, for it is necessary to know both the intensity and direction of the rays. The final positions on the sphere of rays scattered out of the prism are then calculated, and since the intensities of the spots at those points are known, a map of intensity can be built up for a given sphere radius and a particular refractive index. By tracing at different refractive indices, the various colours can be modelled. In using this technique, one piece of information is lost: the position on the stone from which the light came. Thus it is not possible to directly take account of the visible girdle or dark table effects in this approximation. The resultant spot pattern for

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