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Parametric optimal designs of wine glasses using special power functions while reflecting designer's philosophy in advance

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Abstract

Wine glasses are a kind of stemware that is used to drink and taste wine functionally. Nowadays, wine glasses are made mostly from crystallo glass, which makes the color of wine clearly visible. In this study, with the aim of designing wine glasses optimally, they are described mathematically in terms of their geometric parameters, i.e., design parameters and control parameters, and special power functions. The design parameters are used to embed the designer's artistic and functional philosophies at the initial stage of design. The special power functions are introduced to formulate and minimize the weight of the glass while satisfying the required volume constraint precisely. Now, one may have a glass that has almost all desired features in terms of its artistry, aesthetic appeal, function, minimum weight, and precise containing volume. In that case, the geometric parameters may also be used to classify the types of glasses quantitatively without any ambiguity.

Keyword: Wine glasses, Geometric parameters, Design parameters, Control parameters, Power function

INTRODUCTION

Wine glasses are a kind of stemware that is used to drink and taste wine functionally [1]. An early type of wine glass was a clay goblet that was used at the end of the Pleistocene age (11,000 years ago) by the Britons [2]. They then learned to fabricate copper alloy during the Bronze Age and used tankards made of wood and bronze as drinkware. At the beginning of the Roman Empire, the Romans used goblets made of silver and pottery, and they also made goblets out of lead. Then, Saxon goblets made of gold appeared, following which horns, cups, bowls, leather vessels, and various other forms of glasses were developed. In the late 11th century, clear glass cups were commonly used in England [3]. Nowadays, wine glasses are made in various sizes and shapes according to the different kinds of wines, e.g., red, white, and sparkling.

The shapes of wine glasses are designed for effective tasting of the drink and also for aesthetic appeal. The optimal designs of wine glasses imply minimization of their weight while satisfying the constraint for their containing volume and following the artistic and functional philosophies of the designer. Thus far, however, designs of wine glasses are not fully optimal, in the sense that they satisfy the volume constraint approximately and do not meet the exact realization of minimal weights. Moreover, classifications of the shapes of wine glasses are somewhat qualitative. In other words, if one describes the shape of wine glass, it may not be possible to copy its dimension clearly and accurately.

Therefore, this study was conducted in an attempt to describe the shape of wine glasses parametrically; once this is accomplished, then the classification of the types of glasses will not be a complicated task. Wine glasses can be grouped according to the numerical digits of the geometric parameters on which the design is relying. If the shapes of glasses are described parametrically, designing them optimally for their weight minimization while satisfying the volume constraint becomes a straight-forward task. The artistic and functional philosophies of the designer are embedded at the first stage of the parametric design by assigning design parameters to values as necessary.

To represent the shapes of glasses parametrically, we adopted cubic polynomial equations for two divided regions. However, to allow for the infinite gradient at the bottom point of most of the commonly used wine glasses, a special function was applied for that region. Integrations for evaluating the weight or containing volume of the glasses were analytically computed for the simple polynomials, and some numerical techniques were applied to the complex function. The optimally designed wine glasses exhibited minimum weight while satisfying the volume constraint and also complying with the initial philosophy of the designer.

DESIGN PARAMETERS FOR WINE GLASSES

Glasses for drinking red wine are characterized by their round and wide bowl, which promotes oxidation. As oxygen from air chemically interacts with the wine, the flavor and aroma of the wine are expected to be fully developed [4]. This process of oxidation occurs better with red wines, whose combined flavors seem to spread out after being exposed to air. Glasses for drinking white wine vary widely in terms of their size and shape, from the champagne flute to the wide and shallow coupe glasses used to drink vintage champagne. The sherry glass is a stemmed glass with an inverted shallow cone bowl. The wide mouth of the bowl places the surface of the drink directly under the taster's nose to ensure close contact with the aromatic elements of the drink. The hurricane glass is a glass tumbler that is used to serve mixed drinks. It is shaped similar to a hurricane lamp and is usually taller and wider than a highball glass. Similarly, differently shaped glasses are used for different functions and for different kinds of wines.

In this study, in order to represent the shapes of wine glasses, two mathematical functions are adopted for two divided regions, as shown in Figure 1. A profile curve is expressed by two functions: $y_{\mathrm{I}}(x)$ ranging from x_0 to x_1 and $y_{\mathrm{II}}(x)$ ranging from x_1 to x_2. These functions are the radius functions of height of the glass, and therefore, these curves should be continuously differentiable at point x_1.

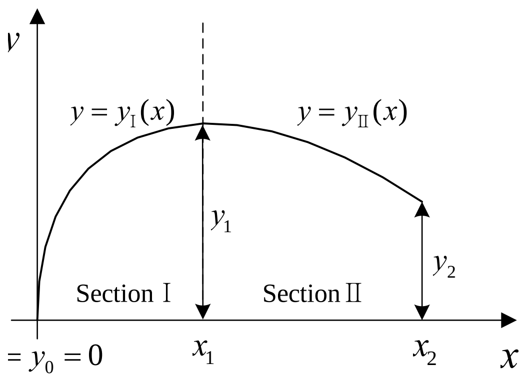


Figure 1. Profile of a typical wine glass

Design parameters (k_x, k_{y1}, k_{y2}, g_1, g_2) considering the aesthetic appeal and use of the wine glasses are described by the following equations in advance:

$$x_2 = k_x \times x_1: \ \textit{height of wine glass}$$
$$y_1 = k_{y1} \times x_1: \ \textit{radius at height } x_1$$
$$y_2 = k_{y2} \times x_1: \ \textit{radius at height } x_2$$
$$y_{\mathrm{II}}'(x_1) = g_1: \ \textit{gradient at height } x_1$$
$$y_{\mathrm{II}}'(x_2) = g_2: \ \textit{gradient at height } x_2$$

where

$$x_0 \sim x_2: \ \textit{height values at three levels of height of wine glass}$$
$$y_0 \sim y_2: \ \textit{radius values at three levels of height of wine glass}$$

The design parameters are pre-given constants that determine the overall styles of the wine glasses. The effects of the design parameters are summarized, and common ranges of these values are given in Table 1. The symbols k_x, k_{y1}, k_{y2}, g_1, and g_2 are the design parameters used to determine the shapes of the wine glasses. They should be provided by designer before performing the optimization of the wine glass.

Table 1. Design parameters representing effects and geometric characteristics of bowls of wine glasses

Design parameter	Effects	Ranges of parameters		
k_x	aesthetic appeal	short top (< 2)	medium top (≈ 2)	long top (> 2)
k_{y1}	carbonation retention, and aesthetic appeal	slender bowl (< 1)	medium bowl (≈ 1)	fat bowl (> 1)
k_{y2}	aromatic effect and aesthetic appeal	small mouth (< 1)	medium mouth (≈ 1)	large mouth (> 1)
g_1	aesthetic appeal	converging waist (< 0)	parallel waist (= 0)	diverging waist (> 0)
g_2	aromatic effect, usability, and aesthetic appeal	retracting top (< g_1)	extended top (≈ g_1)	flared top (> g_1)

FORMULATION OF OPTIMAL DESIGN OF WINE GLASSES WITH CONTROL PARAMETERS

A wine glass is typically composed of three parts: the bowl, stem, and base. In this study, we focus on optimizing the bowl from among these parts to meet the requirements of minimum weight and precise containing volume. The technology necessary for achieving the optimal design of wine glasses is in place at present; however, attempts to develop such optimal designs have not been initiated, because of traditional customs and difficulties in representing infinite gradient at the bottom point and reflecting designer's philosophy. The goal of the present work is to enhance the basic mathematics of wine glass design and systemize the process of optimal design. To this end, profiles of wine bowls are constructed using geometrical parameters (design and control parameters) and the optimal shapes are obtained using the successive zooming genetic algorithm (SZGA) [5, 6]. The flowchart of the SZGA is shown in Figure 2 [7]. The SZGA is a genetic algorithm (GA) with a special feature that can improve convergence by narrowing down the search area successively.

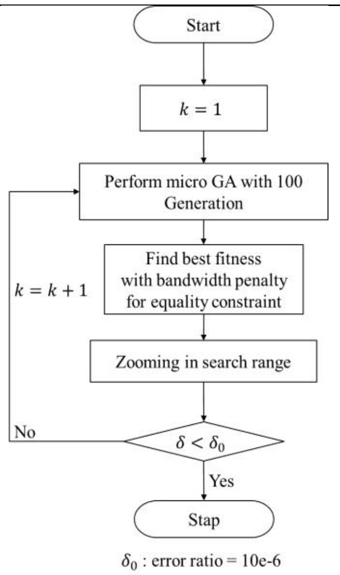


Figure 2. Flowchart of SZGA with equality constraint

The specific mass of the glass is taken as 2,500 kg/m^3. Its thickness is assumed as $t = 1$ *mm*. The formulated optimization problem is to minimize the objective function of weight,

$$F(\mathbf{X}) = 2\pi t\gamma \left[\int_{x_0}^{x_1} y_{\mathrm{I}} \sqrt{1+\left(\frac{dy_{\mathrm{I}}}{dx}\right)^2} dx + \int_{x_1}^{x_2} y_{\mathrm{II}} \sqrt{1+\left(\frac{dy_{\mathrm{II}}}{dx}\right)^2} dx \right] \quad (1)$$

subject to

$$Vol = \pi \left[\int_{x_0}^{x_1} {y_{\mathrm{I}}}^2 dx + \int_{x_1}^{x_2} {y_{\mathrm{II}}}^2 dx \right] = Vol* \quad (2)$$

: *designated containing volume of the glass*

where,

$F(\mathbf{X})$: *weight of the bowl of wine glass*
γ : *specific weight of glass = 2500g N/m*^{3}
$\mathbf{X} = [Z_1, Z_2]^T$: *solution vector* $(0 \le Z_1, Z_2 \le 1)$
Z_1, Z_2 : *dimensionless control parameters*
$x_0 = 0$: *height of the bottom point*
$x_1 = Z_1 \times H$: *height of the top of section I*
H : *reference height of wine glass*
$x_2 = k_x \times x_1$: *height of the top of section II*
y_0 : *radius at the bottom height*
$y_1 = k_{y1} \times x_1$: *radius at height* x_1
$y_2 = k_{y2} \times x_1$: *radius at height* x_2
$k_x, k_{y1}, k_{y2}, g_1, g_2$: *design parameters considering beauty and usage*
$g_0 = 1/Z_2 - 1$: (*primitive*) *gradient at bottom point*
$g_1 = y_{\mathrm{II}}'(x_1)$: *gradient at height* x_1
$g_2 = y_{\mathrm{II}}'(x_2)$: *gradient at height* x_2

The control variable Z_1 controls overall size through the state variable x_1, and control variable Z_2 controls the shape of glass through the (primitive) gradient g_0. The functions $y_{\mathrm{I}}(x)$ and $y_{\mathrm{II}}(x)$ describe the radius profiles of glass along height x as follows.

$$y_{\mathrm{I}}(x) = y_1 \left(\frac{a_0 + a_1 x + a_2 x^2 + a_3 x^3}{y_1} \right)^{(1/n)}, \; (n = 1 \sim 3) \quad (3)$$

$$y_{\mathrm{II}}(x) = b_0 + b_1 x + b_2 x^2 + b_3 x^3 \quad (4)$$

$y_{\mathrm{I}}(x)$, $y_{\mathrm{II}}(x)$: *radius functions of height x in sections I and II*
a_i, b_i : *coefficients of radius functions*

Both functions are based on cubic polynomials [8], the coefficients of which are readily computed from four boundary conditions. In this study, however, for the region I, a special power function of the cubic polynomial raised to the power of (*1/n*) to realize the infinite gradient at the bottom point as in actual wine glasses ($n \neq 1$). When $n=1$ it is cubic polynomial for the glass which has finite gradient at the bottom point. The index n need not necessarily be an integer. The gradient g_0 at the bottom point is the actual gradient when $n=1$, and it is a primitive gradient of cubic polynomial when $n \neq 1$, which is used to compute the coefficients a_i. The primitive gradient is changed to infinity to simulate the actual shape of the wine glass through the power index (*1/n*). In the case that $y_0 > 0$ and $g_0 < 0$, g_0 should be expressed as follows to meet the condition of $0 \le Z_2 \le 1$.

$$g_0 = -1/Z_2 + 1 : \textit{gradient at bottom point} \quad (5)$$

In this optimization of the wine glass by using the SZGA, the input to the SZGA are the design parameters (k_x, k_{y1}, k_{y2}, g_1, g_2), the index n for the convexity of the glass, and its volume as constraints, and the output of the SZGA are primarily the solution vector, and finally the coefficients (a_i, b_i) of the above-described two mathema-tical functions, which form the profile of the wine glass and determine its weight. Every iteration in the SZGA performs integrations to obtain weight and containing volume of the glass analytically or numerically.

Simpson's rule [9] is applied to the power function except to the first sector where the Gaussian quadrature [9, 10] is applied because the integrand is ceased to be finite at an end.

by shapes of contours and boundary conditions with different constraints [7]. The proposed method will be validated through examples.

IMPLEMENTATION OF PROPOSED OPTIMIZATION PROCEDURE

Optimizations of different types of wine glasses with different volumes are performed using the SZGA. They are classified

Table 2. Classification of cases according to the shapes of glasses

Case	Bottom radius	Bottom gradient	Function		Convex upward	Example
			Region I	Region II		
1	0	infinite	power	cubic	yes	Red
2	0	finite	cubic	cubic	yes/ no	Sherry
3	> 0	infinite	power	cubic	yes	Hurricane
4	> 0	finite	cubic	cubic	yes/ no	Weizen

Classification by shape of glass

In the optimization process, cubic polynomial functions are adopted for the two divided regions of the profile of wine glasses. However, a special function is applied in region I in order to make the function closely follow the general shape of the glasses. In particular, this function permits an infinite gradient at the bottom point. Table 2 presents the classification of the cases according to the types of functions and constraints for the shapes of the glasses. The shapes of the wine glasses can be divided into four cases. In cases 1 and 2, the bottom radii are zero and in cases 3 and 4, the bottom radii are greater than zero. In cases 1 and 3, the bottom gradients are infinite and in cases 2 and 4, the bottom gradients are finite. Region II of all cases uses cubic polynomials, and region I of cases 2 and 4, either. The region I of cases 1 and 3 adopts power functions for the infinite bottom gradients. All the convexities at the lower bowl may be upward or downward, except the cases 1 and 3 where the convexities are always upward.

The design parameters are extracted from an actual red wine glass (Table 3). The eight coefficients that minimize the weight of the glass are obtained while satisfying the volume constraint through the SZGA. Subsequently, contours that form the profile of the glass are drawn using the obtained coefficients and the value of n set by the designer. The value of n can usually be selected from among 1, 1.5, 2, and 3, but any other number will do. Figure 3 shows how the convexity of the contour relates to the index, which corresponds to the value of n in Eq. (3). The graph shows the profile of the wine glass at each value of n. Therefore, n is also a pre-given constant decided by the designer like the design parameters. Table 4 presents the weight, capacity, and optimal shape of the glass according to n. The degree of convexity of the bowl varies according to the values of n. Although the capacities of all the glasses be the same, such as 200 *ml*, their shapes and weights are different for different n.

Table 3. Values of design parameter variables for red wine glass

k_x	k_{y1}	k_{y2}	g_1	g_2
1.46	0.61	0.56	0.00	- 0.19

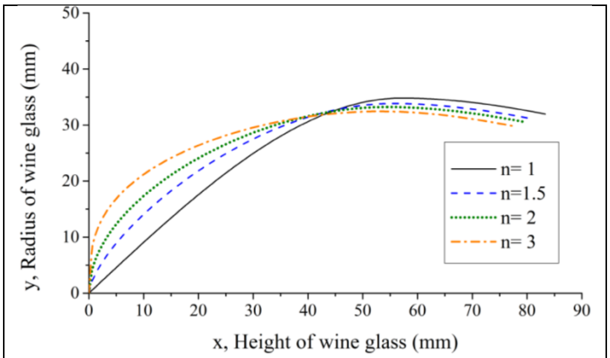


Figure 3. Profiles of wine glass according to the index n

Table 4. Comparison of results with different index of n for the same containing volume

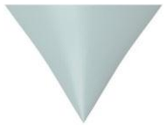
n	Volume [*ml*]	Weight [N]	Optimal shape of glass
1	0.200000E+02	0.355689	
1.5	0.200000E+02	0.358941	
2	0.200000E+02	0.360932	
3	0.200000E+02	0.363971	

Common ranges of design parameters for each type of glass of standard styles

Table 5 summarizes specific common ranges of the design parameters of different types of wine glasses and their shapes as obtained by the SZGA. Various types of wine glasses can be derived by the same optimization procedure using different combinations of the design parameters. It is shown that how the shape of the wine glass is influenced by the design parameters. Furthermore, common design parameters for each type of glass are suggested. Other types of glasses can be developed by adjusting the design parameters provided by the designer.

Table 5. Types of wine glasses and their shapes, represented by design parameters

Type	Specific name	Common ranges of parameters					Shape	$k_x / k_{y1} / k_{y2} / g_1 / g_2$
		k_x	k_{y1}	k_{y2}	g_1	g_2		
Standard	Cabernet Sauvignon	> 2	< 1	< 1	0	$< g_1$		2.21 / 0.78 / 0.58 / 0 / -0.29
	Bordeaux	> 2	< 1	< 1	0	$< g_1$		2.11 / 0.82 / 0.64 / 0 / -0.24
	Burgundy	≈ 2	> 1	< 1	0	$< g_1$		1.89 / 1.08 / 0.90 / 0 /-0.38

	Riesling/Viognier	> 2	≈ 1	< 1	0	$< g_1$		2.74 / 0.98 / 0.74 / 0 /-0.17
Flute	Champagne	> 2	< 1	< 1	0	$\approx g_1$		2.28 / 0.48 / 0.39 / 0 / -0.12
Tulip	Champagne	< 2	< 1	< 1	0	$< g_1$		1.45 / 0.44 / 0.36 / 0 / -0.31
Coupe	Vintage Champagne	< 2	> 1	> 1	0	$< g_1$		1.25 / 1.30 / 1.25 / 0 / -0.23
Hock	Rose/Blush	> 2	≈ 1	< 1	0	$> g_1$		2.23 / 0.88 / 0.76 / 0 / 0.18
Tumbler	Syrah/Shiraz	> 2	≈ 1	< 1	0	$< g_1$		2.60 / 0.95 / 0.69 / 0 / -0.26
Cone	Sherry	≈ 2	< 1	> 1	> 0	$\approx g_1$		2.00 / 0.61 / 1.33 / 0.63 / 0.77

Verification of proposed optimization method

The shape of the wine glass (case 1 of Table 2) is optimized with a volume constraint of 200 *ml*. In order to approximate the shape of the existing red wine glass, the value of *n* is selected as 3 in this case. The optimal model has a height of 77.64 mm and weight of 0.3640 *N*. The values of x_1 and g_0 (primitive gradient) are calculated from the control parameters (Z_1, Z_2) as 53.18 mm and 0.92, respectively. Consequently, the values of y_0, y_1, and y_2 (radii at heights x_0, x_1, and x_2) become 0 *mm*, 32.44 *mm*, and 29.78 *mm*, respectively. Figure 4 shows a comparison of the optimal shape of the red wine glass with the actual one.

Figure 4. Comparison of obtained model with actual red-wine glass

Table 6 presents a comparison of the results of the proposed method with those of other methods: the gradient method and conventional micro-GA included in the commercial package of the Process Integration and Design Optimization (PIDO) software, Process Integration Automation and Optimization (PIAnO) [11]. The proposed method is proven to have a verified accuracy for optimization of the wine glasses.

Table 6. Comparison of results of proposed method with those of other methods included in the commercial package PIAnO

Type of method	Solution vector		Volume [*ml*]	Weight [*N*]
	Z_1	Z_2		
Proposed method	0.531780	0.522183	0.200000E+02	0.363971
Micro-GA (PIAnO)	0.526107	0.447665	0.200000E+02	0.365059
Gradient (PIAnO)	0.531781	0.522192	0.200000E+02	0.363973

Comparison of obtained models with actual wine glasses

Optimal shapes of the glasses are acquired according to different combinations of the design parameters. The shapes of several wine glasses and other particular glasses are obtained from the SZGA by using these parameters. Subsequently, each optimal model is designed and compared with the corresponding actual glass.

Cabernet sauvignon wine glass. The conditions of case 1 (n = 2) in Table 2 are used in this optimization. When the designated volume of the glass is set as 200 *ml*, the optimized model has a height of 88.20 *mm* and weight of 0.2069 *N*. The values of x_1 and g_0 (primitive gradient) are calculated from the control parameters (Z_1, Z_2) as 39.91 mm and 1.57, respectively. Consequently, the values of y_0, y_1, and y_2 (radii at heights x_0, x_1, and x_2) become 0 *mm*, 30.73 *mm*, and 23.15 *mm*, respectively. Table 7 and Figure 5 show a comparison of the obtained model with the actual glass, and give the design parameters used to acquire an optimal design of the Cabernet Sauvignon wine glass.

Table 7. Values of design parameter variables for cabernet sauvignon wine glass

k_x	k_{y1}	k_{y2}	g_1	g_2
2.21	0.78	0.58	0.00	- 0.29

Figure 5. Comparison of obtained model with actual cabernet sauvignon wine glass

Burgundy wine glass. The conditions of case 1 (n = 2) in Table 2 are used in this optimization. When the designated volume of the glass is set as 300 *ml*, the optimized model has a height of 72.59 *mm* and weight of 0.4595 *N*. The values of x_1 and g_0 (primitive gradient) are calculated from the control parameters (Z_1, Z_2) as 38.41 mm and 1.97, respectively. Consequently, the values of y_0, y_1, and y_2 (radii at heights x_0, x_1, and x_2) become 0 *mm*, 41.48 *mm*, and 34.56 *mm*, respectively. Table 8 and Figure 6 show a comparison of the obtained model with the actual glass, and give the design parameters used to acquire an optimal design of the Burgundy wine glass.

Table 8. Values of design parameter variables for burgundy wine glass

k_x	k_{y1}	k_{y2}	g_1	g_2
1.89	1.08	0.90	0.00	- 0.38

Figure 6. Comparison of obtained model with actual burgundy wine glass

Riesling wine glass. The conditions of case 1 (n = 2) in Table 2 are used in this optimization. When the designated volume of the glass is set as 200 *ml*, the optimized model has a height of 86.81 mm and weight of 0.3896 *N*. The values of x_1 and g_0 (primitive gradient) are calculated from the control parameters (Z_1, Z_2) as 31.68 mm and 2.16, respectively. Consequently, the values of y_0, y_1, and y_2 (radii at heights x_0, x_1, and x_2) become 0 *mm*, 31.05 *mm*, and 23.44 *mm*, respectively. Table 9 and Figure 7 show a comparison of the obtained model with the actual glass, and give the design parameters used to acquire an optimal design of the Riesling wine glass.

Table 9. Values of design parameter variables for riesling wine glass

k_x	k_{y1}	k_{y2}	g_1	g_2
2.74	0.98	0.74	0.00	- 0.17

Figure 7. Comparison of obtained model with actual riesling wine glass

Champagne flute. The conditions of case 1 ($n = 2$) in Table 2 are used in this optimization. When the designated volume of the glass is set as 150 *ml*, the optimized model has a height of 111.71 *mm* and weight of 0.3600 *N*. The values of x_1 and g_0 (primitive gradient) are calculated from the control parameters (Z_1, Z_2) as 48.99 mm and 0.83, respectively. Consequently, the values of y_0, y_1, and y_2 (radii at heights x_0, x_1, and x_2) become 0 *mm*, 23.52 *mm*, and 19.11 *mm*, respectively. Table 10 and Figure 8 show a comparison of the obtained model with the actual glass, and give the design parameters used to acquire an optimal design of the Champagne flute.

Table 10. Values of design parameter variables for champagne flute

k_x	k_{y1}	k_{y2}	g_1	g_2
2.28	0.48	0.39	0.00	- 0.12

Figure 8. Comparison of obtained model with actual champagne flute

Champagne coupe. The conditions of case 1 ($n = 2$) in Table 2 are used in this optimization. When the designated volume of the glass is set as 150 *ml*, the optimized model has a height of 39.30 *mm* and weight of 0.2687 *N*. The values of x_1 and g_0 (primitive gradient) are calculated from the control parameters (Z_1, Z_2) as 31.44 mm and 2.60, respectively. Consequently, the values of y_0, y_1, and y_2 (radii at heights x_0, x_1, and x_2) become 0 *mm*, 40.88 *mm*, and 39.30 *mm*, respectively. Table 11 and Figure 9 show a comparison of the obtained model with the actual glass, and give the design parameters used to acquire an optimal design of the Champagne coupe.

Table 11. Values of design parameter variables for champagne coupe

k_x	k_{y1}	k_{y2}	g_1	g_2
1.25	1.30	1.25	0.00	- 0.23

Figure 9. Comparison of obtained model with actual champagne coupe

Comparison of obtained models with actual glasses of non-standard styles

The SZGA is also performed for other actual glasses of non-standard styles, and compared with actual glasses.

Alsace glass. The design parameters used to acquire an optimal design of the alsace glass are given in Table 12. The conditions of case 1 ($n = 3$) in Table 2 are used in this optimization. When the designated volume of the glass is set as 200 *ml*, the optimized model has a height of 51.39 *mm* and weight of 0.3619 *N* (Figure 10). The primitive gradient g_0 is 4.12, which is greater than any other cases.

Table 12. Values of design parameter variables for alsace glass

k_x	k_{y1}	k_{y2}	g_1	g_2
2.73	2.12	1.54	0.00	- 0.42

Figure 10. Comparison of obtained model with actual alsace glass

Hurricane wine glass. The design parameters used to acquire an optimal design of the hurricane wine glass are given in Table 13. The conditions of case 1 ($n = 2$) in Table 2 are used in this optimization. When the designated volume of the glass is set as 200 *ml*, the optimized model has a height of 97.17 *mm* and weight of 0.4131 *N* (Figure 11).

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Table 13. Values of design parameter variables for hurricane wine glass

k_x	k_{y1}	k_{y2}	g_1	g_2
3.16	1.00	0.89	0.00	0.56

Figure 11. Comparison of obtained model with actual hurricane wine glass

Weizen glass (wheat beer glass). The design parameters used to acquire an optimal design of the weizen glass are given in Table 14. The conditions of case 4 in Table 2 are used in this optimization. When the designated volume of the glass is set as 200 *ml*, the optimized model has a height of 148.79 *mm* and weight of 0.4713 *N* (Figure 12).

Table 14. Values of design parameter variables for weizen glass

k_x	k_{y1}	k_{y2}	g_1	g_2
2.83	0.40	0.58	0.00	- 0.25

Figure 12. Comparison of obtained model with actual weizen glass

CONCLUSION

A method for parametric optimal design of different types of wine glasses is developed using cubic polynomials and special power functions for describing the infinite gradient at the bottom point of the glass. The adopted geometric parameters are design parameters, control parameters, and the convexity index. The objective of optimization is to minimize the weight of the glass while satisfying the constraint of the required containing volume. The design philosophy of wine glasses can be established by assigning the design parameters, which are the ratios of the geometric dimensions. This study can be summarized as follows,

1. Wine glasses can be classified into the four following categories, although most of them fall into the category of A-a) (zero bottom radius and infinite gradient).
   A. Zero bottom radius cases:
      a) The gradient at the bottom point is infinite
      b) The gradient at the bottom point is finite
   B. Nonzero bottom radius cases:
      c) The gradient at the bottom point is infinite
      d) The gradient at the bottom point is finite
2. For the newly introduced special power radius function for category a) and c), numerical integration techniques such as Simpson's rule may be applied, except to the first section of the infinite gradient in the radius function. Gauss quadrature is applied to avoid end-point sampling where the gradient is infinite.
3. The designer's artistic and functional philosophies are embedded in the glass design at the earlier stage of the design process by assigning the design parameters, ratios of the geometric dimensions.
4. Application of the proposed systematic method of wine glass design can give optimal control parameters that yield the minimum weight and precise containing volume while complying with the designer's philosophy in advance.

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