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Coefficient Estimates for a Subclass of Bi-univalent Functions Defined by Sălăgean Type q-Calculus Operator

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Abstract

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In this paper, we introduce and investigate a new subclass of bi-univalent functions defined by *Sălăgean q-calculus operator* in the open disk $\mathbb{U}$. For functions belonging to the subclass, we obtain estimates on the first two Taylor-Maclaurin coefficients $|a_2|$ and $|a_3|$. Some consequences of the main results are also observed.
Keywords: analytic functions, bi-univalent functions, coefficient bounds, Sălăgean q-differential operator , Sălăgean derivative.

1. Introduction

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Let $\mathcal{A}$ denote the family of functions *analytic* in the open unit disk

U={z:z∈ℂ and |z|<1},
which are normalized by the condition:
f(0)=f′(0)−1=0
and given by the following Taylor-Maclaurin series:
(1.1)f(z)=z+∑k=2∞ak zk.

Also let $\mathcal{S}$ be the class of functions $f \in \mathcal{A}$ of the form given by (1.1), which are univalent in $\mathbb{U}$. The Koebe one-quarter theorem [7] ensures that the image of $\mathbb{U}$ under every univalent function $f \in \mathcal{S}$ contains a disk of radius 14. Hence every function $f \in \mathcal{S}$ has an inverse

f −1, defined by
f−1(f(z))=z, (z∈U)
and
f−1(f(w))=w, (|w|<r0(f);r0(f)≥14),
where
f−1(w)=w−a2w2+(2a22−a3)w3−(5a23−5a2a3+a4)w4+...

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A function $f \in \mathcal{A}$ is said to be bi-univalent in $\mathbb{U}$ if both f and f^{-1} are univalent in $\mathbb{U}$.

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... the class of bi-univalent functions in $\mathbb{U}$ given by the Taylor-Maclaurin series expansion (1.1). For a brief history and interesting examples of functions in the class Σ, see [28] (see also [4]). From the work of Srivastava *et al.* [28], we choose to recall the following examples of functions in the class Σ:

$$\frac{z}{1-z}, \quad -\log(1-z), \quad \frac{1}{2}\log\left(\frac{1+z}{1-z}\right).$$

However, familiar Koebe function is not a member of Σ.

The class of bi-univalent functions was investigated by Lewin [13], who proved that $|a_2| < 1.51$. In 1981, Styer and Wright [30] showed that $|a_2| > 4/3$. Subsequently, Brannan and Clunie [3] improved Lewin's result to $|a_2| \le \sqrt{2}$. Netanyahu [14], showed that $\max_{f \in \Sigma} |a_2| = \frac{4}{3}$. In 1985, Branges [2] proved Bieberbach conjecture which showed that

$$|a_n| \le n \quad (n \in \mathbb{N} \setminus 1),$$

N being positive integer.

The problem of finding coefficient estimates for the bi-univalent functions has received much attention in recent years. In fact, the aforecited work of Srivastava *et al.* [28] essentially revived the investigation of various subclasses of bi-univalent function class Σ in recent years and that it leads to a flood of papers on the subject (see, for e.g., [6, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29]); it was followed by such works as those by Tang *et al.* [31], Xu *et al.* [32, 33] and Lashin [12], and others (see, for e.g., [1, 5, 8]). The coefficient estimate problem involving the bound of $|a_n|$ ($n \in \mathbb{N} \setminus \{1, 2\}$) for each $f \in \Sigma$ is still an open problem.

In the field of geometric function theory, various subclasses of the normalized analytic function class $\mathcal{A}$ have been studied from different view points. The q-calculus as well as the fractional calculus provide important tools that have been used in order to investigate various subclasses of $\mathcal{A}$. Historically speaking, the firm footing of the usage of the q-calculus in the context of geometric function theory which was actually provided and q-hypergeometric functions were first used in geometric function theory in a book chapter by Srivastava (see, for details, [18, pp. 347 et seq.]). Ismail *et al.* [10] introduced the class of generalized complex functions via q-calculus on some subclasses of analytic functions. Recently, Purohit and Raina [16] investigated applications of fractional q-calculus operator to define new classes of functions which are analytic in unit disk $\mathbb{U}$ (see, for details, [9]).

For $0 < q < 1$, the q-derivative of a function f given by (1.1) is defined as

$$D_q f(z) = \begin{cases} \frac{f(qz) - f(z)}{(q-1)z} & \text{for } z \ne 0, \\ f'(0) & \text{for } z = 0. \end{cases} \tag{1.2}$$

We note that $\lim_{q \to 1^-} D_q f(z) = f'(z)$. From (1.2), we deduce that

$$D_q f(z) = 1 + \sum_{k=2}^{\infty} [k]_q a_k z^{k-1}, \tag{1.3}$$

where as $q \to 1^-$

$$[k]_q = \frac{1 - q^k}{1 - q} = 1 + q + \dots + q^{k} \to k. \tag{1.4}$$

Making use of the q-differential operator for function $f \in \mathcal{A}$, we introduced the Sălăgean q-differential operator as given below

$$D_q^0 f(z) = f(z),\quad D_q^1 f(z) = zD_q f(z),\quad D_q^n f(z) = zD_q(D_q^{n-1} f(z)),\quad D_q^n f(z) = z + \sum_{k=2}^{\infty} [k]_q^n a_k z^k \quad (n \in \mathbb{N}_0, z \in \mathbb{U}). \tag{1.5}$$

We note that $\lim_{q \to 1^-}$

$$D^n f(z) = z + \sum_{k=2}^{\infty} k^n a_k z^k \quad (n \in \mathbb{N}_0, z \in \mathbb{U}), \tag{1.6}$$

the familiar Sălăgean derivative [17].

Recently, Kamble and Shrigan [11] introduce the following two subclasses of the bi-univalent function class Σ and obtained estimate on first two Taylor-Maclaurin coefficients $|a_2|$ and $|a_3|$ for functions in these subclasses as follows.

Definition 1.1 ([11])

For $0 < \alpha \le 1$, $0 < q < 1$, $\lambda \ge 1$, $\mu \ge 0$ and $n \in \mathbb{N}_0$, a function $f(z)$ given by (1.1) is said to be *in the class* $\mathcal{H}_\Sigma^{q,\mu}(n, \alpha, \lambda)$ if the following conditions are satisfied

$$f \in \Sigma \text{ and } \left|\arg\left((1-\lambda)\left(\frac{D_q^n f(z)}{z}\right)^{\mu} + \lambda (D_q^n f(z))' \left(\frac{D_q^n f(z)}{z}\right)^{\mu-1}\right)\right| < \frac{\alpha\pi}{2} \tag{1.7}$$

and

$$\left|\arg\left((1-\lambda)\left(\frac{D_q^n g(w)}{w}\right)^{\mu} + \lambda (D_q^n g(w))' \left(\frac{D_q^n g(w)}{w}\right)^{\mu-1}\right)\right| < \frac{\alpha\pi}{2}, \tag{1.8}$$

where the function g is given by

$$g(w) = w - a_2 w^2 + (2a_2^2 - a_3) w^3 - (5a_2^3 - 5a_2 a_3 + a_4) w^4 + \dots \tag{1.9}$$

and D_q^n is the Sălăgean q-differential operator.

Theorem 1.2 ([11])

Let $f(z)$ given by (1.1) be in the function class $\mathcal{H}_\Sigma^{q,\mu}(n, \alpha, \lambda)$. Then

$$|a_2| \le \frac{2\alpha}{\sqrt{\alpha(2(2\lambda+\mu)[3]_q^n - (\lambda^2+2\lambda+\mu)[2]_q^{2n}) + (\lambda+\mu)^2[2]_q^{2n}}} \tag{1.10}$$

and

$$|a_3| \le \frac{4\alpha^2}{(\lambda+\mu)^2[2]_q^{2n}} + \frac{2\alpha}{(2\lambda+\mu)[3]_q^n},$$

where $0 < \alpha \le 1$, $0 < q < 1$, $\lambda \ge 1$, $\mu \ge 0$ *and* $n \in \mathbb{N}_0$.

Definition 1.3 ([11])

For $0 \le \beta < 1$, $0 < q < 1$, $\lambda \ge 1$, $\mu \ge 0$ and $n \in \mathbb{N}_0$, a function $f(z)$ given by (1.1) is said to be *in the class* $\mathcal{H}_\Sigma^{q,\mu}(n, \beta, \lambda)$ if the following conditions are satisfied

$$f \in \Sigma \text{ and } \mathrm{Re}\left((1-\lambda)\left(\frac{D_q^n f(z)}{z}\right)^{\mu} + \lambda (D_q^n f(z))' \left(\frac{D_q^n f(z)}{z}\right)^{\mu-1}\right) > \beta \tag{1.12}$$

and

$$\mathrm{Re}\left((1-\lambda)\left(\frac{D_q^n g(w)}{w}\right)^{\mu} + \lambda (D_q^n g(w))' \left(\frac{D_q^n g(w)}{w}\right)^{\mu-1}\right) > \beta. \tag{1.13}$$

Theorem 1.4 ([11])

Let $f(z)$ given by (1.1) be in the function class $\mathcal{H}_\Sigma^{q,\mu}(n, \beta, \lambda)$. Then

(1.14)|a2|≤min{4(1-β)|2[3]qn+(μ-1)[2]q2n(2λ+μ)|,2(1-β)(λ+μ)[2]qn}

and

(1.15)|a3|≤min{4(1-β)2(λ+μ)2[2]q2n+2(1-β)(2λ+μ)[3]qn, 2(1-β) |4[3]qn+[2]q2n(μ-1)|-[2]q2n(|μ-1|)|2[3]qn+(μ-1)[2]q2n|(2λ+μ)[3]qn}

where 0 < q < 1, λ ≥ 1, μ ≥ 0 *and* n ∈ ℕ

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Remark 1.5

By appropriately specializing the parameters in Definition 1.1 and 1.3, we can get several known subclasses of the bi-univalent function class ∑. For example:

For *n* = 0 and *q* → 1 , we obtain the bi-univalent function classes 𝓗Σ1,μ(0,α,λ)=NΣμ(α,λ) and 𝓗Σ1,μ(0,β,λ)=NΣμ(β,λ)(*see* [21]);
For μ = 1, *n* = 0 and *q* → 1 , we obtain the bi-univalent function classes 𝓗Σ1,1(0,α,λ)=𝓑Σ(α,λ) and 𝓗Σ1,1(0,β,λ)=𝓑Σ(β,λ)(*see* [8]);
For μ = 1 and *q* → 1 , we obtain the bi-univalent function classes 𝓗Σ1,1(n,α,λ)=𝓑Σ(n,α,λ) and 𝓗Σ1,1(n,β,λ)=𝓑Σ(n,β,λ)(*see* [15]);
For μ = 1, *n* = 0, λ = 1 and *q* → 1 , we obtain the bi-univalent function classes 𝓗Σ1,1(0,α,1)=𝓗Σα and 𝓗Σ1,1(0,β,1)=𝓗Σ(β)(*see* [28]);
For μ = 0, *n* = 0, λ = 1 and *q* → 1 , we obtain the bi-univalent function classes 𝓗Σ1,0(0,α,1)=SΣ*(α) and 𝓗Σ1,0(0,β,1)=SΣ*(β)(*see* [4]);

This paper is a sequel to some of the aforecited works (especially see [11, 32, 33]). Here we introduce and investigate the general subclass 𝓗Σh,p(λ,μ,n,q) (0<q<1,λ≥1,μ≥0) of the analytic function class $\mathcal{A}$, which is given by Definition 1.6 below.

Definition 1.6

Let *h*, $\mathbb{U} \to \mathbb{C}$ be analytic functions and

min{Re(h(z)),Re(p(z))}>0 (z∈U) and h(0)=p(0)=1.

Also let the function *f* given by (1.1), be in the analytic function class $\mathcal{A}$. We say thatf∈𝓗Σh,p(λ,μ,n,q) (0<q<1,λ≥1,μ≥0 and n∈ℕ0)
if the following conditions satisfied:
(1.16)f∈Σ and (1-λ) (Dqnf(z)z)μ+λ(Dqnf(z))'(Dqnf(z)z)μ-1∈h(U) (z∈U)
and
(1.17)(1-λ) (Dqng(w)w)μ+λ(Dqng(w))'(Dqng(w)w)μ-1∈p(U) (w∈U),
where the function *g* is given by (1.9).
If f∈𝓗Σh,p(λ,μ,n,q), then
(1.18)f∈Σ and |arg((1-λ) (Dqnf(z)z)μ+λ(Dqnf(z))'(Dqnf(z)z)μ-1)|<απ2
and
(1.19)|arg((1-λ) (Dqng(w)w)μ+λ(Dqng(w))'(Dqng(w)w)μ-1)|<απ2
or
(1.20)f∈Σ and Re((1-λ) (Dqnf(z)z)μ+λ(Dqnf(z))'(Dqnf(z)z)μ-1)>β
and
(1.21)Re((1-λ) (Dqng(w)w)μ+λ(Dqng(w))'(Dqng(w)w)μ-1)>β,
where the function *g* is given by (1.9).
Our paper is motivated and stimulated especially by the work of Srivastava *et al.* [21, 28]. Here we propose to investigate the bi-univalent function subclass 𝓗Σh,p(λ,μ,n,q) of the function class ∑ and find estimates on the initial coefficients $|a_2|$ and $|a_3|$ for functions in the new subclass of the function class ∑ using Sălăgean *q*-differential operator.

2. A Set of General Coefficient Estimates

In this section, we derive estimates on the initial coefficients $|a_2|$ and $|a_3|$ for functions in subclass 𝓗Σh,p(λ,μ,n,q) given by Definition 1.6.

Theorem 2.1

*Let the function f(z) given by Taylor-Maclaurin series expansion (1.1) be in the function class*𝓗Σh,p(λ,μ,n,q). *Then*
(2.1)|a2|≤min{|h'(0)|2+|p'(0)|22(λ+μ)2[2]q2n,|h''(0)|+|p''(0)|2(2λ+μ)|(μ-1)[2]q2n+2[3]qn|}

and
(2.2)|a3|≤min{|h'(0)|2+|p'(0)|22(λ+μ)2[2]q2n+|h''(0)|+|p''(0)|4(2λ+μ)[3]qn,|(μ-1)[2]q2n+4[3]qn| |h''(0)|+|μ-1||2]q2n|p''(0)|4(2λ+μ)[3]qn|(μ-1)[2]q2n+2[3]qn|},
where 0 < *q* < 1, λ ≥ 1, μ ≥ 0 *and n* ∈ $\mathbb{N}_0$.
Proof
It follows from (1.16) and (1.17) that
(2.3)(1-λ) (Dqnf(z)z)μ+λ(Dqnf(z))'(Dqnf(z)z)μ-1=h(U)
and
(2.4)(1-λ) (Dqng(w)w)μ+λ(Dqng(w))'(Dqng(w)w)μ-1=p(U)
Comparing the coefficients of *z* and z^2 in (2.3) and (2.4), we have
(2.5)(λ+μ) [2]qna2=h1,(2.6)(μ-1) (λ+μ2) [2]q2na22+(2λ+μ) [3]qna3=h2,(2.7)-(λ+μ) [2]qna2=p1
and
(2.8)-(2λ+μ) [3]qna3+(4[3]qn+(μ-1) [2]q2n) (λ+μ2) a22=p2.
From (2.5) and (2.7), we obtain
(2.9)h1=-p1
and
(2.10)2(λ+μ)2[2]q2na22=h12+p12.
Also, from (2.6) and (2.8), we find that
(2.11)((μ-1) [2]q2n+2[3]qn) (2λ+μ)2a22=h2+p2.
Therefore, we find from the equations (2.10) and (2.11) that
|a2|≤|h'(0)|2+|p'(0)|22(λ+μ)2[2]q2n
and
|a2|≤|h''(0)|+|p''(0)|2(2λ+μ)|(μ-1) [2]q2n+2[3]qn|,
respectively. So we get the desired estimate on the coefficients $|a_2|$ as asserted in (2.1).
Next, in order to find the bound on the coefficient $|a_3|$, we subtract (2.8) from (2.6), we get

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(2.12)2(2λ+μ) [3]qna3-2[3]qn(2λ+μ)a22-h2-p2.

Upon substituting the value of a22 from (2.10) into (2.12), we arrive at

(2.13)|a3|≤|h'(0)|2+|p'(0)|22(λ+μ)2[2]q2n+|h''(0)|+|p''(0)|4(2λ+μ) [3]qn.

... into (2.12), we arrive at

a3-[(μ-1) [2]q2n-4[3]qn]h2+(μ-1) [2]q2np22(2λ+μ) [3]qn[(μ-1) [2]q2n+2[3]qn].

Consequently, we have

(2.14)|a3|≤|(μ-1) [2]q2n+4[3]qn| |h''(0)|+|μ-1| [2]q2n|p''(0)|4(2λ+μ) [3]qn |(μ-1) [2]q2n+2[3]qn|.

This evidently completes the proof of Theorem 2.1.

3. Corollaries and Consequences

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By Setting $\mu = 1$, $q \to 1^-$ and $n = 0$ in Theorem 2.1, we deduce the following consequence of Theorem 2.1.

Corollary 3.1

Let the function f(z) given by Taylor-Maclaurin series expansion (1.1) be in the function class 𝓑Σh,p(λ) (λ≥1). *Then*

(3.1)|a2|≤min{|h'(0)|2+|p'(0)|22(1+λ)2,|h''(0)|+|p''(0)|4(1+2λ)}

and

(3.2)|a3|≤min{|h'(0)|2+|p'(0)|22(1+λ)2+|h''(0)|+|p''(0)|4(1+2λ),|h''(0)|2(1+2λ)}.

By Setting $\mu = 0$, $\lambda = 1$, $q \to 1^-$ and $n = 0$ in Theorem 2.1, we deduce the following.

Corollary 3.2.([5])

Let the function f(z) given by Taylor-Maclaurin series expansion (1.1) be in the function class 𝓑Σh,p. *Then*

(3.3)|a2|≤min{|h'(0)|2+|p'(0)|22,|h''(0)|+|p''(0)|4}

and

(3.4)|a3|≤min{|h'(0)|2+|p'(0)|28+|h''(0)|+|p''(0)|8,3|h''(0)|+|p''(0)|8}.

Remark 3.3

Corollary 3.2 is an improvement of the following estimates obtained by Xu *et al.* [33].

Corollary 3.4.([33])

Let the function f(z) given by Taylor-Maclaurin series expansion (1.1) be in the function class 𝓑Σh,p(λ) (λ≥1). *Then*

(3.5)|a2|≤|h''(0)|+|p''(0)|4(1+2λ)

and

(3.6)|a3|≤|h''(0)|2(1+2λ).

By Setting $\lambda = 1$, $\mu = 1$, $q \to 1^-$ and $n = 0$ in Theorem 2.1, we deduce the following Corollary 3.5.

Corollary 3.5.([32])

Let the function f(z) given by Taylor-Maclaurin series expansion (1.1) be in the function class 𝓗Σh,p. *Then*

(3.7)|a2|≤|h''(0)|+|p''(0)|12

and

(3.8)|a3|≤|h''(0)|6.

4. Concluding Remarks and Observations

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The main objective in this paper has been to derive first two Taylor-Maclaurin coefficient estimates for functions belonging to a new subclass 𝓗Σh,p(λ,μ,n,q) of analytic and bi-univalent function in the open unit disk $\mathbb{U}$. Indeed, by using *Sălăgean q-calculus operator*, we have successfully determined the first two Taylor-Maclaurin coefficient estimates for functions belonging to a new subclass 𝓗Σh,p(λ,μ,n,q).

By means of corollaries and consequences which we discuss in the preceding section by suitable specializing the parameters λ and μ, we have also shown already that the results presented in this paper would generalize and improve some recent works of Xu *et al.* [32, 33] and other authors.

Acknowledgements

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