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CERTAIN SUBCLASS OF BI-UNIVALENT FUNCTIONS DEFINED BY q-DERIVATIVE OPERATOR INVOLVING POISSON DISTRIBUTION

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ABSTRACT. In this paper, by using the q-derivative operator, we define a new subclass of bi-univalent functions involving Poisson distribution series associated with Horadam polynomials. We find estimates for the general Taylor-Maclaurin coefficients and also Fekete-Szegö problem for this class.

Keywords: Univalent and Bi-univalent functions, Fekete-Szegö inequality, Poisson distribution, Horadam polynomials and q-derivative operator.

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1. Introduction

Let $\mathcal{A}$ denote the class of the functions f of the form

$$f(z) = z + \sum_{n=2}^{\infty} a_n z^n, \tag{1}$$

which are analytic in the open unit disc $\mathbb{D} = \{z \in \mathbb{C}; |z| < 1\}$ and satisfy the normalization condition $f(0) = f'(0) - 1 = 0$.

Let $\mathcal{S}$ be the subclass of $\mathcal{A}$ consisting of functions of the form (1) which are also univalent in $\mathbb{D}$. According to the Koebe's one-quarter theorem [2], every function $f \in \mathcal{S}$ has an inverse f^{-1} defined by

$$f^{-1}(f(z)) = z \qquad (z \in \mathbb{D})$$

and

$$f(f^{-1}(w)) = w \qquad \left(|w| < r_0(f); r_0(f) \geq \frac{1}{4}\right),$$

where

$$g(w) = f^{-1}(w) = w - a_2 w^2 + (2a_2^2 - a_3)w^3 - (5a_2^3 - 5a_2 a_3 + a_4)w^4 + ... \tag{2}$$

A function $f \in \mathcal{A}$ is said to be bi-univalent in $\mathbb{D}$ if both f and its inverse f^{-1} are univalent in $\mathbb{D}$. Let Σ denote the class of bi-univalent functions in $\mathbb{D}$ given by (1). For more basic results one may refer Srivastava et al. [12] and references there in.

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Next, we recall the definition of subordination between analytic functions. For two functions $f, g \in \mathcal{A}$, we say that f is subordinate to g in $\mathbb{D}$, written as $f \prec g$ provided there is an analytic function w in $\mathbb{D}$ with $w(0) = 0$ and $|w(z)| < 1$ such that $f(z) = g(w(z))$. It follows from Schwarz Lemma that

$$f(z) \prec g(z) \iff f(0) = g(0) \quad and \quad f(\mathbb{D}) \subset g(\mathbb{D}), \quad z \in \mathbb{D}.$$

For $q \in (0, 1)$, the Jackson q-derivative of a function $f \in \mathcal{A}$ is given by (see, for example, [6, 7]):

$$D_q f(z) = \begin{cases} \frac{f(qz)-f(z)}{(q-1)z} & (z \neq 0), \\ f'(0) & (z = 0). \end{cases} \tag{3}$$

Thus from (3), we have

$$D_q f(z) = 1 + \sum_{n=2}^{\infty} [n]_q a_n z^{n-1} \tag{4}$$

where

$$[n]_q = \frac{1 - q^n}{1 - q},$$

and, as $q \to 1^-$, $[n]_q \to n$.

Recently, Hörzum and Kocer [5] studied the Horadam polynomials $h_n(x)$, which are given by the following recurrence relation (see, for example, [4, 11, 3]):

$$h_n(x) = \rho x h_{n-1}(x) + \sigma h_{n-2}(x) \quad (x \in \mathbb{R}; \quad n \in \mathbb{N} = \{1, 2, 3, ...\}) \tag{5}$$

with

$$h_1(x) = a \quad and \quad h_2(x) = bx,$$

for some real constants a, b, ρ and σ. Moreover, the generating function of the horadam polynomials $h_n(x)$ is given by

$$\Pi(x, z) = \sum_{n=1}^{\infty} h_n(x) z^{n-1} = \frac{a + (b - a\rho)xz}{1 - \rho xz - \sigma z^2} \tag{6}$$

Remark 1.1. *We record here some special cases of the Horadam polynomials $h_n(x)$ by appropriately choosing the parameters a, b, ρ and σ.*

- *(i) Taking $a = b = \rho = \sigma = 1$, we obtain the Fibonacci polynomials $F_n(x)$.*
- *(ii) Taking $a = 2, b = \rho = \sigma = 1$, we get the Lucas polynomials $L_n(x)$.*
- *(iii) Taking $a = \sigma = 1$ and $b = \rho = 2$, we have the Pell polynomials $P_n(x)$.*
- *(iv) Taking $a = b = \rho = 2$ and $\sigma = 1$, we find the Pell-Lucas polynomials $Q_n(x)$.*
- *(v) Taking $a = b = 1, \rho = 2$ and $\sigma = -1$, we obtain Chebyshev polynomials $T_n(x)$ of first kind.*
- *(vi) Taking $a = 1, b = \rho = 2$ and $\sigma = -1$, we have Chebyshev polynomials $U_n(x)$ of second kind.*

A variable x is said to have Poisson distribution if it takes the values $0, 1, 2, 3, ...$ with probabilities

$$e^{-m}, m\frac{e^{-m}}{1!}, m^2\frac{e^{-m}}{2!}, m^3\frac{e^{-m}}{3!}, ...$$

respectively, where m is called the parameter.
Thus

$$P(x = r) = \frac{m^r e^{-m}}{r!}, \qquad r = 0, 1, 2, 3, ..$$

Recently, Porwal [9] introduced a power series whose coefficients are probabilities of Poisson distribution

$$K(m,z)=z+\sum_{n=2}^{\infty}\frac{m^{n-1}}{(n-1)!}e^{-m}z^n,\quad (m>0, z\in\mathbb{D}).$$

We note that, by ratio test, the radius of convergence of the above series is infinity. In 2016, Porwal and Kumar [10] introduced a new linear operator $I(m,z):A\to A$ which is defined as follows

$$I_m f(z)=K(m,z)*f(z)=z+\sum_{n=2}^{\infty}\frac{m^{n-1}}{(n-1)!}e^{-m}a_n z^n,\quad (m>0, z\in\mathbb{D}),$$

where $*$ denote the convolution (or Hadamard product) of two series.

The object of the present paper is to introduce a new subclass of Σ involving the Poisson distribution associated with Horadam polynomials $h_n(x)$. We obtain the estimates on the initial Taylor-Maclaurin coefficients and the Fekete-Szegö inequalities for this subclass of the bi-univalent function class Σ defined by means of the Horadam polynomials.

Definition 1.1. *For $0<q<1$ and $0\le\lambda\le 1$, a function $f\in\Sigma$ is said to be in the class $\mathcal{H}_\Sigma(\lambda,m,x,q)$ if it satisfies the following conditions:*

$$\frac{(1-\lambda)zD_q(I_m f(z))+\lambda zD_q(zD_q(I_m f(z)))}{(1-\lambda)I_m f(z)+\lambda zD_q(I_m f(z))}\prec\Pi(x,z)+1-a$$

and

$$\frac{(1-\lambda)wD_q(I_m g(w))+\lambda wD_q(zD_q(I_m g(w)))}{(1-\lambda)I_m g(w)+\lambda wD_q(I_m g(w))}\prec\Pi(x,w)+1-a,$$

where a is real constant and the function $g=f^{-1}$ is given by (2).

Example 1.1. *For $\lambda=0$ and $0<q<1$, a function $f\in\Sigma$ is said to be in the class $\mathcal{H}(0,m,x,q)=:\mathcal{S}_\Sigma(m,x,q)$ if it satisfies the following conditions:*

$$\frac{zD_q(I_m f(z))}{I_m f(z)}\prec\Pi(x,z)+1-a$$

and

$$\frac{wD_q(I_m g(w))}{I_m g(w)}\prec\Pi(x,w)+1-a.$$

where a is real constant and the function $g=f^{-1}$ is given by (2).

Example 1.2. *For $\lambda=1$ and $0<q<1$, a function $f\in\Sigma$ is said to be in the class $\mathcal{H}(1,m,x,q)=:\mathcal{K}_\Sigma(m,x,q)$ if it satisfies the following conditions:*

$$\frac{D_q(zD_q(I_m f(z)))}{D_q(I_m f(z))}\prec\Pi(x,z)+1-a$$

and

$$\frac{D_q(wD_q(I_m g(w)))}{D_q(I_m g(w))}\prec\Pi(x,z)+1-a.$$

where a is real constant and the function $g=f^{-1}$ is given by (2).

2. MAIN RESULTS

Theorem 2.1. *For $0 < q < 1$ and $0 \le \lambda \le 1$, let $f \in \mathcal{A}$ be in the class $\mathcal{H}_\Sigma(\lambda, m, x, q)$. Then*
$|a_2| \le$

$$\frac{|bx|\sqrt{2|bx|}}{\sqrt{|(bm^2e^{-m}\phi(\lambda,m) - 2\rho m^2 e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2)\,bx^2 - 2\sigma a m^2 e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2|}}$$

and

$$|a_3| \le \frac{1}{m^2e^{-m}}\left(\frac{2|bx|}{(1+\lambda([3]_q-1))([3]_q-1)} + \frac{b^2x^2}{e^{-m}(1+\lambda([2]_q-1))^2([2]_q-1)^2}\right),$$

where

$$\phi(\lambda,m) = (1+\lambda([3]_q-1))([3]_q-1) - 2e^{-m}(1+\lambda([2]_q-1))^2([2]_q-1) \tag{7}$$

Proof. Let $f \in \mathcal{H}_\Sigma(\lambda, m, x, q)$. Then there are two analytic functions $u, v : \mathbb{D} \to \mathbb{D}$ given by

$$u(z) = u_1z + u_2z^2 + u_3z^3 + ... \qquad (z \in \mathbb{D}) \tag{8}$$

and

$$v(w) = v_1w + v_2w^2 + v_3w^3 + ... \qquad (w \in \mathbb{D}), \tag{9}$$

with $u(0) = v(0) = 0$ and $\max\{|u(z)|, |v(w)| < 1\}$ $(z, w \in \mathbb{D})$, such that

$$\frac{(1-\lambda)zD_q(I_mf(z)) + \lambda zD_q(zD_q(I_mf(z)))}{(1-\lambda)I_mf(z) + \lambda zD_q(I_mf(z))} = \Pi(x, u(z)) + 1 - a$$

and

$$\frac{(1-\lambda)wD_q(I_mg(w)) + \lambda wD_q(zD_q(I_mg(w)))}{(1-\lambda)I_mg(w) + \lambda wD_q(I_mg(w))} = \Pi(x, v(w)) + 1 - a,$$

or, equivalently, that

$$\frac{(1-\lambda)zD_q(I_mf(z)) + \lambda zD_q(zD_q(I_mf(z)))}{(1-\lambda)I_mf(z) + \lambda zD_q(I_mf(z))} = h_1(x) + h_2(x)u(z) + h_3(x)(u(z))^2 + ... + 1 - a \tag{10}$$

and

$$\frac{(1-\lambda)wD_q(I_mg(w)) + \lambda wD_q(zD_q(I_mg(w)))}{(1-\lambda)I_mg(w) + \lambda wD_q(I_mg(w))} = h_1(x) + h_2(x)v(w) + h_3(x)(v(w))^2 + ... + 1 - a. \tag{11}$$

Combining (8),(9),(10) and (11), we find that

$$\frac{(1-\lambda)zD_q(I_mf(z)) + \lambda zD_q(zD_q(I_mf(z)))}{(1-\lambda)I_mf(z) + \lambda zD_q(I_mf(z))} = 1 + h_2(x)u_1z + [h_2(x)u_2 + h_3(x)u_1^2]z^2 + ... \tag{12}$$

and

$$\frac{(1-\lambda)wD_q(I_mg(w)) + \lambda wD_q(zD_q(I_mg(w)))}{(1-\lambda)I_mg(w) + \lambda wD_q(I_mg(w))} = 1 + h_2(x)v_1w + [h_2(x)v_2 + h_3(x)v_1^2]w^2 + ... \tag{13}$$

It is well- known that, if

$$\max\{|u(z)|, |v(w)|\} < 1 \quad (z, w \in \mathbb{D}),$$

then

$$|u_j| \le 1 \qquad \textit{and} \qquad |v_j| \le 1 \quad (\forall j \in \mathbb{N}). \tag{14}$$

Now, by comparing the corresponding coefficients in (12) and (13) and after some simplification, we have

$$[1+\lambda([2]_q-1)]me^{-m}([2]_q-1)a_2 = h_2(x)u_1, \tag{15}$$

$$[1+\lambda([3]_q-1)]\frac{m^2}{2!}e^{-m}([3]_q-1)a_3 - [1+\lambda([2]_q-1)]^2m^2e^{-2m}([2]_q-1)a_2^2 = h_2(x)u_2 + h_3(x)u_1^2, \tag{16}$$

$$-[1+\lambda([2]_q-1)]me^{-m}([2]_q-1)a_2 = h_2(x)v_1 \tag{17}$$

and

$$[1+\lambda([3]_q-1)]\frac{m^2}{2!}e^{-m}([3]_q-1)(2a_2^2-a_3)-[1+\lambda([2]_q-1)]^2m^2e^{-2m}([2]_q-1)a_2^2 = h_2(x)v_2+h_3(x)v_1^2. \tag{18}$$

It follows from (15) and (17) that

$$u_1=-v_1 \tag{19}$$

and

$$2[1+\lambda([2]_q-1)]^2m^2e^{-2m}([2]_q-1)^2a_2^2=(h_2(x))^2(u_1^2+v_1^2). \tag{20}$$

If we add (16) to (18), we find hat

$$2\frac{m^2}{2}e^{-m}\phi(\lambda,m)a_2^2=h_2(x)(u_2+v_2)+h_3(x)(u_1^2+v_1^2), \tag{21}$$

where $\phi(\lambda,m)$ is given by (7).
Upon substituting the value of $u_1^2+v_1^2$ from (20) into the right-hand side of (21), we deduce that

$$a_2^2=\frac{(h_2(x))^3(u_2+v_2)}{2\left\{m^2e^{-m}\phi(\lambda,m)(h_2(x))^2-m^2e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2h_3(x)\right\}}. \tag{22}$$

By further computations using (5) (14)and (22), we obtain

$|a_2|\le$

$$\frac{|bx|\sqrt{2|bx|}}{\sqrt{|(bm^2e^{-m}\phi(\lambda,m)-2\rho m^2e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2)\,bx^2-2\sigma a m^2e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2|}}.$$

Next if we subtract (18) from (16), we can easily see that

$$2\frac{m^2}{2}e^{-m}(1+\lambda([3]_q-1))([3]_q-1)(a_3-a_2^2)=h_2(x)(u_2-v_2)+h_3(x)(u_1^2-v_1^2). \tag{23}$$

In view of (19) and (20), we find from (23) that

$$a_3=\frac{h_2(x)(u_2-v_2)}{2\frac{m^2}{2}e^{-m}(1+\lambda([3]_q-1)([3]_q-1))}+\frac{(h_2(x))^2(u_1^2+v_1^2)}{2m^2e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2}.$$

Thus, by applying (5), we obtain

$$|a_3|\le\frac{1}{m^2e^{-m}}\left(\frac{2|bx|}{(1+\lambda([3]_q-1))([3]_q-1)}+\frac{b^2x^2}{e^{-m}(1+\lambda([2]_q-1))^2([2]_q-1)^2}\right).$$

□

In the next theorem we discuss Fekete-Szegö inequality for $f\in\mathcal{H}_\Sigma(\lambda,m,x,q)$.

Theorem 2.2. *For $0<q<1$, $0\le\lambda\le1$ and $x,\mu\in\mathbb{R}$, let $f\in\mathcal{A}$ be in the class $\mathcal{H}_\Sigma(\lambda,m,x,q)$. Then*

$$|a_3-\mu a_2^2|\le\begin{cases}\frac{2|bx|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)}; \\ \left(|\mu-1|\le\frac{|[bm^2e^{-m}\phi(\lambda,m)-2\rho m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2]bx^2-2\sigma a m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)b^2x^2}\right) \\ \frac{2|bx|^3|\mu-1|}{|[bm^2e^{-m}\phi(\lambda,m)-2\rho m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2]bx^2-2\sigma a m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2|}; \\ \left(|\mu-1|\le\frac{|[bm^2e^{-m}\phi(\lambda,m)-2\rho m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2]bx^2-2\sigma a m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)b^2x^2}\right).\end{cases}$$

Proof. It follows from (22) and (23) that

$$a_3-\mu a_2^2=\frac{h_2(x)(u_2-v_2)}{2\frac{m^2}{2}e^{-m}(1+\lambda([3_q-1])([3]_q-1))}+(1-\mu)a_2^2$$

$$=\frac{h_2(x)(u_2-v_2)}{2\frac{m^2}{2}e^{-m}(1+\lambda([3]_q-1))([3]_q-1)}$$

$$+\frac{h_2(x)^3(u_2+v_2)(1-\mu)}{2\left[\frac{m^2}{2}e^{-m}\phi(\lambda,m)(h_2(x))^2-m^2e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2h_3(x)\right]}$$

$$= \frac{h_2(x)}{2}\left[\left(\Omega(\mu,x) + \frac{1}{\frac{m^2}{2}e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)}\right)u_2 \right.$$
$$\left. + \left(\Omega(\mu,x) - \frac{1}{\frac{m^2}{2}e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)}\right)v_2\right],$$

where

$$\Omega(\mu,x) = \frac{(h_2(x))^2(1-\mu)}{\frac{m^2}{2}e^{-m}\phi(\lambda,m)(h_2(x))^2 - m^2e^{-2m}(1+\lambda([2]_q-1))^2([2]_q-1)^2h_3(x)}.$$

Thus, according to (5), we have

$$|a_3-\mu a_2^2| \le \begin{cases} \frac{2|bx|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)} & 0 \le |\Omega(\mu,x)| \le \frac{2}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)} \\ |bx||\Omega(\mu,x)| & |\Omega(\mu,x)| \ge \frac{2}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)}, \end{cases}$$

after some computation, we obtain

$$|a_3-\mu a_2^2| \le \begin{cases} \frac{2|bx|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)}; \\ \left(|\mu-1| \le \frac{|[bm^2e^{-m}\phi(\lambda,m)-2\rho m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2]bx^2-2\sigma a m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)b^2x^2}\right) \\ \frac{2|bx|^3|\mu-1|}{|[bm^2e^{-m}\phi(\lambda,m)-2\rho m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2]bx^2-2\sigma a m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2|}; \\ \left(|\mu-1| \ge \frac{|[bm^2e^{-m}\phi(\lambda,m)-2\rho m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2]bx^2-2\sigma a m^2e^{-2m}[1+\lambda([2]_q-1)]^2([2]_q-1)^2|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)b^2x^2}\right). \end{cases}$$

□

Putting $\mu = 1$ in Theorem 2.2, we obtain the following result.

Corollary 2.1. *For $0 < q < 1$, $0 \le \lambda \le 1$ and $x \in \mathbb{R}$, let $f \in \mathcal{A}$ be in the class $\mathcal{H}_\Sigma(\lambda,m,x,q)$. Then*

$$|a_3 - a_2^2| \le \frac{2|bx|}{m^2e^{-m}[1+\lambda([3]_q-1)]([3]_q-1)}.$$

Remark 2.1. *We can derive analogous results for normalized analytic and bi-univalent functions in the class $\mathcal{H}_\Sigma(\lambda,m,x,q)$ associated with the Poisson distribution series by taking some or all of the particular cases of the Horadam polynomial as shown in Remark 1.1 and using the same technique as in Section 2 above. Furthermore the results can be deduced by appropriately specialising the parameter λ for the subclasses $\mathcal{S}_\Sigma(m,x,q)$ and $\mathcal{K}_\Sigma(m,x,q)$, which are defined in Example 1.1 and 1.2 respectively.*

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